INTEGRATED RENEWABLE RESOURCE MANAGEMENT FOR U.S. INSULAR AREAS

Volume II: Commissioned Papers

Part E: Aquatic Resources

1. The Role of Marine Resource Tenure Systems (TURFs) in Sustainable Nearshore Marine Resource Development and Management in U.S.-Affiliated Pacific Islands
   (Robert Johannes)
2. Aquaculture and Mariculture Development in the U.S. Pacific Insular Areas
   (Stephen G. Nelson)
3. The Development and Management of Nearshore Fisheries in the U.S.-Affiliated Pacific Islands
   (Paul Callaghan)
4. Non-Food Marine Resources Development and Management in the U.S.-Affiliated Pacific Islands
   (Barry Smith)
5. Aquaculture Development in the U.S.-Affiliated Islands
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6. Aquaculture and Fisheries Development in Puerto Rico and the U.S. Virgin Islands
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7. Non-Food Marine Resources Development and Management in the U.S.-Affiliated Caribbean Islands
   (Charles Wahle)
8. Applicability of Zeolite Refrigeration Systems to Small Tropical Islands
   (Dimiter Tchernev)

December 1986

These Commissioned Papers were prepared by the outside contractors as an input to an ongoing Office of Technology Assessment (OTA). They do not necessarily reflect the analytical findings of OTA, the Advisory Panel, or the Technology Assessment Board

J952-36

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Background Paper No. 1

THE ROLE OF MARINE RESOURCE TENURE SYSTEMS (TURFS) IN SUSTAINABLE NEARSHORE MARINE RESOURCE DEVELOPMENT AND MANAGEMENT IN U.S.-AFFILIATED TROPICAL PACIFIC ISLANDS

(Author's Draft)

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

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1. INTRODUCTION

Managing a resource involves regulating the behavior of the people whose activities affect that resource. In order to do so effectively it is necessary to study not only the resource itself, but also the local customs and institutional arrangements associated with its use. Conservation laws and resource management schemes that are compatible with local practices will gain more public acceptance than those perceived by users as alien. Public support is especially important in developing tropical countries because money and personnel available for enforcement is generally minimal.

Here I describe a millenia-old system of allocation of marine resources found in many of the U.S.-affiliated Tropical Pacific Islands (USATPI). In contrast with Western tradition, Pacific islanders have traditionally owned the right to restrict or control fishing activities in their shallow water fishing grounds. Such fishing rights are sometimes referred to today by fisheries researchers as TURFs, an acronym for "traditional use rights in fisheries". A belated recognition of the importance of TURFs in the context of contemporary marine resource management has emerged only within the past few years. Before developing this subject I will first describe the specific characteristics of TURFs operating on USATPI.

2. DESCRIPTION OF SPECIFIC TENURE SYSTEMS

2.1. CAROLINE ISLANDS

In the Caroline Islands it is useful for the purposes of this report to consider separately two types of island society. 1. administrative and population centers, typically on larger islands and with populations of several to tens of thousands, and 2. small outlying islands, typically with populations of a few hundred people.

2.1.1. Main Population Centers

2.1.1.1. Yap

Yap is a high island with a population of about 7,000 living in numerous small coastal villages as well as in the district center of Colonia. Yapese customs pertaining to traditional fishing rights are probably more complex than anywhere else among USATPI. A comprehensive study of Yapese fishing rights would probably take several years and fill a large book.

Yap is divided into a number of ranked districts and villages, the inhabitants being ranked accordingly (Falanruw, 1968).

According to Sudo (1984) the inshore waters of Yap are divided by each village boundary, which extends directly from the village through the lagoon and reef to the open ocean. Boundaries inside the reef are defined by passages or channels through the fringing reef. Outsiders are strictly prohibited from exploiting the resources of this area. Villagers may seize the catch and gear of any trespasser. Falanruw (personal communication, 1981) says that even trespassers' boats may be seized. In earlier times trespassers were sometimes killed.

Sudo (†984, p. 219, 225) states, "a Yapese estate usually consists of one or more houses, several taro patches (maut), yam gardens (milay), coconut palms (niw), grassy uplands (tayid), forests (egaragar), tracts of sea inside the reef (daay) and stone fish weirs (ech). The eldest man of a patri-lineage heads the estate and has nominal control over all estate land. The Yapese consider these associated land and sea resources as a single unit.

"There are three well-defined status levels among chiefs, each with definite roles in controlling marine resources. The "Chief of the Village," the highest rank, has important rights to exercise general control over inshore waters. His supreme rights are acknowledged by gifts from the catch obtained by communal fishing and fish trapping.

"The "Chief of Fishing,"* of second rank, is the status which leads communal fishing in the open sea. The statuses to lead fishing and to exercise magical ritual in fishing are appendant to the privilege to receive a portion of the catch. And the "Overseer of Fishing" has the right to direct communal fishing inside the lagoon. He has the privilege to take more shares than the other participants. It is interesting that those statuses are assigned to particular estates.

"On the other hand the right to use inshore waters is sub-divided. The fishing rights in reef flat areas are controlled by particular families. Small-scale fishing is allowed to every villager but for communal fishing permission must be obtained from the "Overseer of Village Sea Land." The tracts inside reefs are parcelled out and owned by particular families."

The lowest Yapese class, the pimelingai, owned no fishing grounds and were restricted from using all but the most primitive fishing gear (e.g. pointed sticks). They were allowed to gather seafood only in streams and estuaries. They could eat only eels, octopus, sharks, rays and other fishes which could not be eaten by the higher classes. They had to report any "high class" fish they caught to the appropriate higher class authority (Falanruw, 1968 and personal communication 1975).

In Raang Village, where fishing rights were studied in some detail by Sudo (1984), certain extended families, usually of high ranking estates "own" and oversee all fishing grounds within the reef. Fishing rights are parcelled out to various estates and careful distinction is made among the methods of customs have died out. But it is not always clear just how strong the various customs are today. It does appear, however, that overall village fishing boundaries are still upheld vigorously.

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* An anonymous reviewer suggests that this term may not be correct, but does not indicate what term should be used. Perhaps M. or S. Falanruw can clarify this.

Destructive fishing using dynamite or bleach is sometimes carried out on Yap reefs. One Yap municipality reacted by advertising on the local radio stating that anyone found doing this in their waters would have their boats confiscated (Falanruw, personal communiations, 1975). The Yap newspaper also occasionally mentions disputes over fishing rights. At least one dispute reached the High Court, Yap District (Yangruw and Giltaman vs Manggur and Fenam, Civil Action No. 23 (1961)).

2.1.1.2. Palau

Palau is an archipelago consisting of limestone and volcanic islands - most of them within a large lagoon - plus two atolls. The population is about 14,000. I carried out research on traditional fishing rights in Palau in the early 1970's.

Each of Palau's village clusters, called municipalities, exercises the right to limit access to its adjacent fishing grounds. (Within at least one municipality (Ngaraard) further subdivisions were made in this century so that individual villages have control of adjacent fishing grounds). These fishing rights are still maintained, in most municipalities, to just beyond the outer reef dropoff. The lateral boundaries of municipal fishing grounds are shown in Figure 1. Up until the turn of the century, when the custom of shark fishing miles offshore died out, fishing rights extended in theory to the outer limit of foraging seabirds resident on Palau, or about 75-150 miles (Nakayama and Ramp, 1974). The need to defend this vague outer boundary arose rarely if ever.

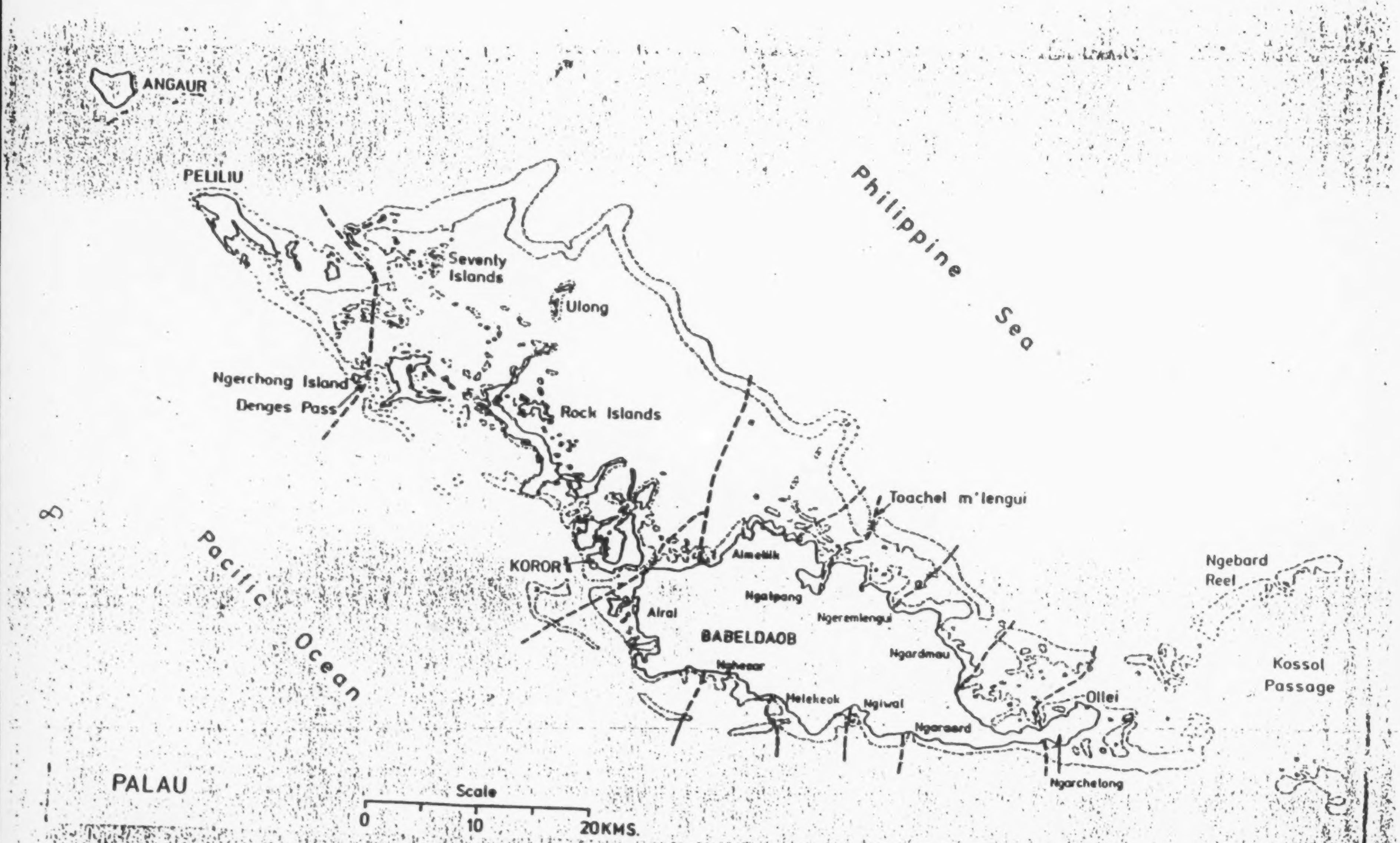

ANGAUR
PELILIU
Philippine Sea
Seventy Islands
Ulong
Ngerchong Island
Denges Pass
Rock Islands
Toachel m'lengui
KOROR
Almeliik
Ngatpang
Airai
BABELDAOB
Ngeremlengui
Ngardmau
Ngchesar
Melekeok
Ngiwal
Ngaraard
Ollei
Ngarchelong
Ngebard Reef
Kossol Passage
Pacific Ocean
PALAU
Scale
0
10
20KMS.

Figure 1. Municipal TURF boundaries in Palau

Traditional fishing rights are controlled by the chiefs for the benefit of the villagers they represent. A municipality concerned about poachers will sometimes broadcast a warning to them over the local radio station. Continued poaching can lead to the chief of a poacher's village being fined by one of Palau's traditional high chiefs. The fined chief thereby loses face, and the clan of the fisherman who caused this embarrassment is made to pay for it - usually in the form of a substantial amount of cash. Formerly hostilities between neighboring districts often precluded the observations of these niceties, and the offenders, if caught, forfeited their lives.

The system was not inflexible however. The use by others of marine resources surplus to the needs of the owners could be arranged. Fishermen were sometimes allowed to fish in their neighbor's waters providing they asked permission and agreed to pay a portion of the catch. (Today some municipalities forbid outsiders to fish commercially in their waters but allow visitors to fish there for their own needs. Such arrangements are common in Oceania).

Sharing of fishing resources sometimes went beyond temporary fishing permits to the outright gift of fishing grounds to less well-endowed villages. For example, in about 1930 the municipality of Ngeremlengui ceded fishing rights to two reef and lagoon areas surplus to their needs to the neighboring district of Ngatpang.

McCutcheon (1981, p. 115) provides another example of the flexibility (and vicissitudes) of the traditional reef and lagoon tenure system in Palau: "(The municipality of) Melekeok never had any shortage of trochus-rich reefs, but its southern neighbor, Ngchesar, had none. Through a long-standing agreement, the reef off Ngchesar's shores belonged to Melekeok. According to legend, the hamlet of Ngerang in Melekeok once came to the military aid of

Ngaruingel village in Ngchesar. To repay Ngerang for this help, Ngaruingel gave up its reef as teliakl payment - payment of land or money in compensation for service in war. The reef became known as Idimes ("southern") as affirmation of its ownership by Melekeok.

"As trochus became more and more valuable a trade item, the residents of Ngchesar began to help themselves to the wealth that Idimes reef harbored. The poaching began during the Japanese administration, but created a real annoyance to Melekeok in the 1950's. There were some insults exchanged by the chiefs in power, and a payment of money to a chief of Melekeok was made to acknowledge wrong doing and indebtedness and to assure future use rights. In this way, title by Melekeok has been confirmed, and use rights in perpetuity by Ngchesar were acquired."

McCutcheon (1981) points out that had trochus not been a valuable resource, such a problem would never have resulted in the explicit definition of the villages' respective rights.

Fishing grounds may be shared by two districts. For example, Kossol and Ngerael reefs have traditionally been jointly fished by the people of Kayangel and Ngercherong. Also, fishermen from Ngeremlengui and Ngardmau may exploit one another's trochus resources commencing three days after the opening of trochus season (Kaneshiro, 1958).

Formerly subsidiary fishing rights within TURFs, to rock fish traps, and to particular fishing areas, were owned by individuals or corporate kin groups (Johannes, 1981a; McCutcheon, 1981). These subsidiary rights are rarely taken seriously today and often not even remembered.

2.1.1.3. Truk

Truk is a complex of volcanic and coral islands in a lagoon encircled by a fringing reef. Fourteen islands are permanently inhabited by a total population of about 35,000. According to Sudo (1984, p. 217), "The reef flat and seaward margin are the most important fishing grounds, and are strictly sub-divided into several named sections. Each section is owned and controlled by a particular lineage. Although such property as sand or rock is owned exclusively by lineages, fishing rights in those sections are open to all villagers. Women gather shellfish and carry out hand net fishing. On the other hand, the fishing rights to the seaward margin are limited to members of the lineage owning that section. If men obtain a catch in the reef sections owned by another lineage they are obliged to present several fishes to the owner of that section."

2.1.1.4. Ponape

Ponape is a high island with associated small islands surrounded by a barrier reef. The total population is about 20,000. The following description of traditional sea rights comes from Fischer (1968). Each of five municipalities had exclusive fishing rights in adjacent waters. Trespassing sometimes led to warfare. At certain times in the history of Ponape, municipalities' sea rights were so severely enforced that travel by water was virtually impossible.

In aboriginal times the municipal boundaries were marked all the way out to the outer reef. On the outer reef, piles of coral showed the traveller or fishermen when he passed from one municipality to another. These customs died out around the turn of the century, apparently because of suppression by German colonists, although the former lateral boundaries of municipal fishing grounds are still described in each municipality's charter (Johannes, unpub.).

Although many Ponapean fishermen and municipal leaders I talked to in 1978 favored the reintroduction of some form of fishing rights, subsequent deliberations by Ponape fisheries authorities led to the conclusion that 20th century changes in Ponapean society and demography made the practicality of such a move doubtful. (They feared, according to an anonymous reviewer, that the marine equivalent of a "land grab" might result).

2.1.1.5. Kosrae

I have never come across anything of value written concerning traditional fishing or fishing rights on Kosrae. Gawel (personal communication, 1983) states, "lack of the old traditions of reef tenure and of fishing taboos in Kosrae makes it more important there for the government and communities to develop new management techniques to protect marine resources."

2.1.2. Outlying Caroline Islands

Information on TURFs exists for only a few of the outer Caroline Islands.

2.1.2.1. Ulithi Atoll

Ulithi lies 160 km northeast of Yap. A total of about 700 persons inhabit five of the 30 islets on the atoll. According to Sudo (1984) the atoll is divided politically into eight districts, each composed of several villages and one or more islets. Districts are ranked and Mogmog is the senior district. The paramount chief of Mogmog has some jurisdiction over the entire atoll. Districts were reportedly apportioned among the chief of each clan by the paramount chief, who set aside for each several reefs, lagoons and islands. The chiefs of each district control marine resources on behalf of the paramount chief (Ushijima, 1982).

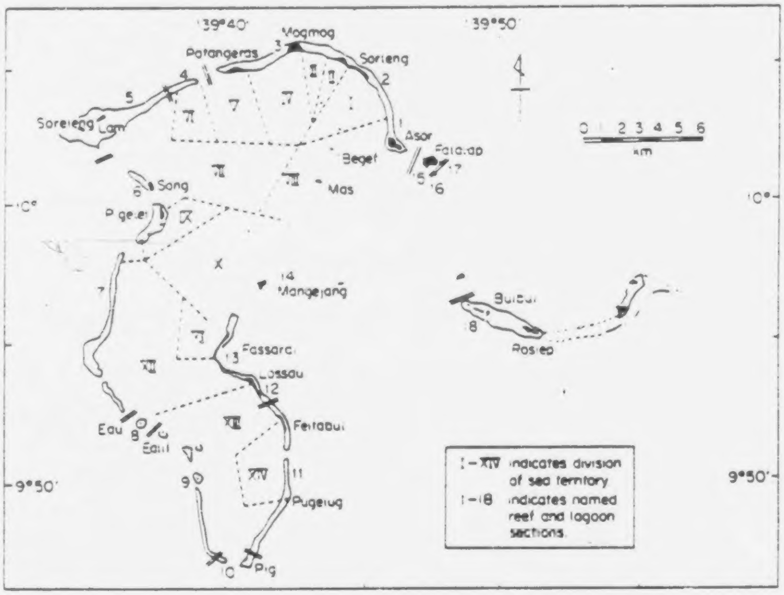
The lagoon and reef areas of the atoll are divided into 14 lagoon and 18 reef sections. Figure 2 is a copy of a map provided by Sudo (1984) showing these subdivisions as drawn by Ushijima (1982). Members of clans in any district or island have fishing rights in those reef and lagoon areas belonging to their clan. The authority of the paramount chief is acknowledged by periodic gifts of specified fish. No one may partake of the catch until the proper presentation has been made (Lessa, 1950; Akimichi and Sauchoman, 1982).

2.1.2.2. Satawal

Satawal is an isolated, small, raised coral island with a population of about 500. The people are grouped into eight clans. The chiefs of the three highest-ranking clans share the responsibility for planning and controlling resource use. One of these, the "Chief of the Sea" takes most of the responsibility for regulating fishing activities.

In the vicinity of Satawal, according to Sudo (1984), men are usually free to fish anywhere, whereas the women are limited to fishing within the reef. Occasionally the Chief of the Sea will prohibit the use of spears in an area.

Fishing activities on more distant fishing grounds are more strictly regulated. Fishing on Wenimong Reef is restricted to special occasions, for example. In general men who wish to visit uninhabited islands or remote reefs must obtain prior approval from the Chief of the Sea. The latter has proprietary rights to certain species in these areas as well as the authority to determine how and when fishing shall be carried out (Sudo, 1984).


139°40'
139°50'
Mogmog
3
Potangeras
Sorleng
2
4
5
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Lam
I
II
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IV
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VI
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VIII
IX
X
XI
XII
XIII
XIV
1
Asor
Falalap
Beget
Mas
15
16
17
6
Song
Pigelel
10°
14
Mangejang
Bulbul
18
Rosiep
7
Fassarai
13
Lossau
12
Feitabul
Eau
8
Eaut
9
11
Pugelug
10
Pig
9°50'
0 1 2 3 4 5 6
km
I – XIV indicates division of sea territory
1 – 18 indicates named reef and lagoon sections.

Figure 2. Reef and Lagoon Sections on Ulithi Atoll
[after USHIJIMA 1982]

2.1.2.3. Woleai

Woleai is a small atoll lying about half way between Truk and Palau. According to Alkire (1968, p. 57, 58): "The lagoon is a controlled area. Boundaries conceptually divide it into segments, each of which is under the stewardship of one of the chiefs of the atoll. The chief, as a guardian of the lagoon divisions, has the right to restrict certain kinds of fishing in the area he controls as in the case of a funeral ceremony, for example, where he can prohibit fishing altogether for a specified period of time......

"In many ways an atoll dweller considers reef areas as more important than the lagoon itself.....

"Large coral heads which protrude from the lagoon floor, independent of the encircling atoll reef, are termed moto. These too are individually named and they are usually owned by the clan or sub-division thereof that has stewardship over the area of the lagoon in which they are found. The controlling lineage, sub-clan, or clan of specific moto has the right to restrict the number of fish-trap placed in their vicinity. There are about 30 moto within Woleai Lagoon."

2.1.2.4. Etal Atoll

Etal Atoll in the Mortlock Islands had a population of 446 in 1980. Sudo (1984) described the regulation of fishing. The reef flats and reef slopes are divided into small named tracts owned by one of the eight clans or sub-clans, who have exclusive fishing rights to them. Five fish weirs are owned by particular clans. The catch from these weirs is usually distributed to all clan members by the clan chief. Permission by one clan to use a section of reef or a weir owned by another is sometimes granted upon request. A portion of the subsequent catch must be given to the owners.

According to Sudo (1984, p. 216, citing Nason, 1971), "Since the paramount chief of Etal holds proprietary rights over the lands and inshore waters, he can place a taboo over one section of the reef off Etal islet in times of food scarcity or to commemorate the death of a prominent man. The chiefs of each district also possess proprietary rights to place taboos on particular reef sections within each district. These taboos are designed to conserve marine resources."

2.1.2.5. Namonuito Atoll

Namonuito Atoll comprises five inhabited islands 230 northwest of Truk. Sudo (1984) has described briefly the regulation of fishing on one of them, Ulul, which had a population of 276 people in 1976.

All islanders are permitted to fish anywhere, using any method, with the exception of one area which is exclusively owned by the chief's clan. Members of this clan use it mainly to catch octopus for bait, but the area is sometimes opened to all islanders for a communal fish drive. The chief is responsible for controlling marine resources and directing communal fishing.

Nothing has apparently been recorded concerning fishing relations between the populations of Ulul and the four other inhabited islands of the atoll.

2.1.2.6. Lukunor Atoll

During German colonial occupation of Lukunor Atoll traditional fish rights lapsed. I do not know the reason - perhaps German governmental edict as in Ponape (see above). In any event, at the beginning of the American administration a chief set out to restore the fish trapping and reef fishing areas to those who had formerly controlled them.

According to Tolerton and Rauch (1949, p. 95, 96), "This was not popular with the people, who in the last generation and particularly during the war had become accustomed to considerable freedom in the use of the lagoon, and particularly of the reef area adjacent to the islands. Also while not everyone had trapping grounds, their ownership was sufficiently widespread through "companies" so that all shared more or less equally in their produce. However, only 12 people controlled the reef area, and five the great majority, three of whom were closely related to the chief. Re-establishment of control meant that one must go through the routine of asking permission before using it and render a token tribute of one's catch. The order was particularly resented because the area is that utilized most intensely by the women and boys whose contribution was important during the scarcity induced by wartime dynamiting and people wished no restriction on gleaning. Yet this was precisely the reason, and undoubtedly a just one, given by the chief for the order restoring the former ownership pattern, for he felt the young men particularly were not giving the fish a chance to rest and multiply, and that they and the women were taking too many of the shellfish, which are the only readily available food after a typhoon. It is also true that traditionally the chief's have felt identified with the reef area, it is "their" land and it hurts to see it being abused by careless people. But those without an interest in such property charged that the chiefs and other owners were interested in obtaining a monopoly and that the people could then only buy fish in "cafes", and appealed to the Civil Affairs Office in Truk, upon which the chief rescinded the order."

According to Sudo (1984) fishing rights on Lukunor Atoll are almost identical to those of Etal (see above).

2.2. MARIANA ISLANDS

We know only the barest outline of the traditional culture of the original inhabitants of the Mariana islands because Spanish colonization led to a reduction of the population by about 90% through introduced disease and warfare. The remainder, mostly women and children, were shifted to Guam. Saipan was subsequently recolonized by Carolineans from the Woleai to Namonuito region. Today the population of Saipan is about 20% of Carolinian origin, about 80% of Chamorro-Spanish origin (Alkire, 1984).

According to Thompson (1945, p. 12) "nobles" among Chamorros on Guam "apparently" controlled much if not all of the district lands and fishing grounds. She cites Freycinet (1829-37) as stating that fishing rights were rigidly enforced; each fisherman was assigned fishing grounds with boundaries fixed by alignments taken on land, and death was the penalty for fishing out of bounds.

There is no recollection today in these islands of a local tradition of sea rights, nor have such customs been imported by the Carolinian population. Unless certain modern *de facto* sea rights customs have evolved (I am unaware of any after having interviewed fishermen on Guam, Saipan, Tinian and Rota) any form of limited entry for the purposes of fisheries management would have to be formulated without reference to local tradition.

2.3. MARSHALL ISLANDS

The Marshall Islands consist of 29 atolls and five raised coral islands spread out over an area of about 750,000 km^2. The total land area is only 120 km^2 and the population was about 30,000 in 1980.

According to Tobin (1958) reefs throughout the Marshalls were claimed as personal property by the paramount chief if fishing was good around them. After this taboo was instituted, no one else was permitted to fish the particular reef on penalty of death or expulsion from his land. Otherwise, property rights extended out into the water to the area where people stood, usually waste deep, in order to fish with a pole. These rights belonged exclusively to the lineage whose land holding bordered the marine area (Tobin, 1952).

Certain unpopulated islands and the reefs around them were set aside as reserves for the protection of seabirds and their eggs (both eaten by the Marshallese), nesting turtles, coconut crabs and crayfish, harvesting being allowed only on occasions designated by the chiefs (Kramer, 1906; Tobin, 1952).

These customs continued until 1934 when Japanese authorities declared that all marine areas, up to the high water mark, belonged to the Japanese government. According to Tobin (1952, p. 12), "this break with tradition has continued under the American trusteeship and is apparently accepted by everyone today." Nevertheless, "the concept that the right to exploit the marine resources of an atoll is the prerogative of the inhabitants of that atoll still persists" (Tobin, 1958, p. 69).

2.4. AMERICAN SAMOA

von Bulow in an obscure German paper published in 1902 provides the only description we have of traditional fishing rights in Samoa. All Samoan fishing grounds have their owners, he stated. Reefs and portions of reefs were variously owned by communities, chiefs' families or other individuals. Trespassing was punished by the "local assembly".

von Bulow (1902, p. 40, 41) continued, "fishing rights are generally considered as non-saleable in Samoa. Nevertheless in the 1807's it happened that native fishing grounds were surrendered to strangers; this however, in part without obtaining the assent of the state.........

"These fishing grounds make up part of the wealth of the owner and therefore should be protected by law today just as much as any other possession - something which until this day has actually been the case in the villages.

"Fishing rights entitle the owner to every kind of fishing on his fishing ground, to the piling up of coral and stone heaps as hiding places for fish, and to setting up any number of fish and crab traps.

"The duties of an owner of a fishing ground are in general the following:

1. If he catches certain large species of fish (the turtle, laumei, is also considered as "fish" - ia) he has to turn them over to the village assembly or in some villages to particular chiefs or to particular speakers (translator's note - "talking chiefs?").

2. In addition he has to follow the orders of the village assembly if for a certain period it forbids the catching of atule (South Sea Herring) in order for the assembly to gain time to prepare to catch this fish in the lauloa (a large drag-net), or

3. if the assembly declares the ocean "forbidden" - sa - because a high chief has died, or because during the transfer of the remains of a long-deceased person from the present grave to a new grave his bones were "bathed" by the sea.

4. The owner has to allow his own village or neighbouring localities to cast their large drag-net, but to do so without searching through the stone heaps he has set up himself,

5. as well as to allow everyone to cross his fishing ground while dragging a fishing lure, pa, any time of day or night."

Although the impact of westernization has fallen especially heavily on American Samoa, some elements of traditional sea rights apparently continue to function. Thus Wass (1982, p. 81) states, "village councils occasionally limit fishing on the reefs fronting their village through a temporary ban on fishing or by prohibition of fishermen from other villages. Several villages do not allow fishing on Sundays and most prohibit the use of dynamite and poison, especially chlorine bleach. Management regulations instituted on the village level are much more effective than those of the territorial or federal governments because they are promulgated within the cultural context by traditional leaders and, consequently, are more likely to receive the approval and fealty of the villagers."

3. DISCUSSION

My task here is to try to describe the relevance of TURFs to contemporary marine resource management. It would be nice to be able to set out a list of relevant conclusions and recommendations for each island or island group. But this is not practical; our knowledge of these systems is too fragmentary.

Needed, along with better information on the contemporary status of traditional sea rights practices, is more detailed local knowledge of the relevant aspects of marine resource use (locations, species, quantities, harvested, methods used, distribution of the catch, the relation between the size of the fishery and of the resource base, the effects of adjacent or overlapping commercial fisheries etc.).

In addition the knowledge we do possess is not sufficiently up to date; conditions are changing rapidly in these islands as a consequence of Westernization and political reorganization. Even studies done as little as eight or ten years ago (e.g. Johannes, 1981a; McCutcheon, 1981) cannot be assumed to reflect adequately the state of affairs today.

There is thus no substitute for detailed, locale-specific studies of the current state of traditional sea rights and how they fit into the complex and varied sets of biological, political, economic, cultural and geographic factors relevant to marine resource management. Nevertheless a variety of useful lessons and helpful general guidelines emerge from what we do know about these systems.

Some writers have described how TURFs provide a means for maintaining or improving the welfare of small fishing communities by facilitating sound marine resource management (e.g. Cordell, 1974; Johannes, 1977; Christy, 1982 and many others). These researchers point out that where TURFs exist it is in the best interests of those who control them not to overfish. The penalty for doing so - reduced future catches - accrues directly to the owners. Self-interest thus dictates conservation. Where such resources are available to everyone, in contrast, it is in the best interests of fishermen to catch all they can. Since they cannot control the activities of other fishermen, the fish they refrain from catching will most likely be caught by someone else. In a fishery open to all self-interest dictates overfishing.

Pacific islanders anticipated the West's discovery of this principle by many centuries. This is almost certainly because, firstly, the islanders, unlike continental peoples, depended upon the sea for something like 90% of their animal protein and, secondly, the sea's productivity around small isolated islands is limited largely to a narrow fringe of coral reefs. Thus the marine resources associated with small oceanic islands are much more liable to overexploitation than those of continental shelves. As Brower (1974, p. 46) has said, "Islanders perceive their limits more easily than do continental peoples."

In the West, recognition that there were practical limits to the sea's productivity developed only around the turn of the last century (e.g. Nielsen, 1976). An awareness of how unrestricted entry to a fishery contributed to stock depletion did not gain momentum until fifty years later when Gordon (1954) clearly described the benefits of limited entry. Hardin (1968) extended this analysis to all renewable resources, terrestrial and aquatic, and described the depletion resulting from unlimited access to limited natural resources with the now familiar phrase "the tragedy of the commons."

For the past 25 years a gradually expanding campaign has been waged by Western economists and biologists to introduce limited entry in Western commercial fisheries. And for the past ten years a growing collection of economists, anthropologists and marine biologists has been pointing out that non-western systems of limited entry to fisheries, i.e. TURFs, have existed for centuries, but that many of these have, ironically, been destroyed or are under threat today because of the impacts of Westernization.

In the past five years a number of fisheries biologists have argued that TURFs can pose an impediment to fisheries management and development; traditional owners may lock up underused marine resources, excluding the outside capital and expertise needed for their more effective exploitation (Haines, 1982; Polunin, 1984; Wright, 1985).

These contrasting views might be perceived as fundamentally contradictory and thus confusing to fisheries managers who look to researchers for advice on the subject. This would be unfortunate and unnecessary. The two points of view are based much less on differing interpretations of the facts than on different sets of facts. Systems of traditional fishing rights are very diverse. Some, accordingly, are more useful in fisheries management than others.

Whether TURFs are, in general, a boon or a bane for fisheries managers should thus not be an issue. The real question is, how can a specific system of traditional fishing rights contribute usefully to contemporary fisheries management?

The number of disputes over access to fishing grounds increases as populations grow, fishing technology improves and pressures on resources push their potentials for sustained yields to the limit. This is the case in many shallow water fisheries of the USATPI. Where TURFs exist in this setting the fisheries manager must determine where they fit in the contemporary management structure.

Here I suggest: 1. how to go about answering this question for a particular system of traditional fishing rights, 2. why TURFs cannot simply be ignored or eliminated by legislative fiat, and 3. how these considerations pertain to the fisheries of USATPI.

3.1. ASSESSMENT

There are four basic questions that must be answered in order to assess the role in contemporary fisheries management of a system of traditional fishing rights.

1. Can or does the TURF contribute to fisheries conservation?

As discussed above, the limited entry afforded by TURFs can facilitate fisheries conservation. But it cannot guarantee it. TURFs are not always seen by their owners as a means of facilitating conservation. Carrier (1981), Haines (1982), Polunin (1984) and Wright (1985) have pointed out that TURF owners in areas of Papua New Guinea and Indonesia often appear to employ these rights not as a means of conserving scarce resources, but for political or social ends having little to do with conservation. They point out that indeed, marine resources were not generally limited in these areas; population densities have been comparatively low and/or terrestrial sources of animal protein comparatively high. These authors find little evidence for the existence of a strong traditional ethic of marine conservation among these peoples. We are presently finding a similar state of affairs among the Torres Strait Islanders (Johannes and MacFarlane, unpub.).

Perhaps a conservation ethic cannot be expected to flourish in a society where the supply of renewable natural resources greatly exceed the needs of the population. This situation has not and does not apply in the great majority of oceanic islands in the Pacific however. And in contrast to the findings of researchers in Papua New Guinea and Indonesia, there is plenty of evidence for the existence of a well articulated traditional conservation ethic in Polynesia (e.g. American Samoa) and Micronesia. In fact, most basic marine conservation measures developed in the West in the past century have been practiced for centuries in these islands - closed seasons, closed areas, gear restrictions, size restrictions etc. (see Johannes, 1978, for review).

This should not be taken to imply that Pacific islanders enjoyed a perfect relationship with nature and that all their actions were governed by wisdom and restraint. Environmentally destructive practices coexisted with efforts to conserve natural resources (Johannes, 1978) as they do in Western societies. But the existence of the former does not diminish the significance of the latter.

TURFs, therefore, contribute to fisheries conservation in USATPI.

2. Does the TURF facilitate equitable allocation of the resources?

Pacific Island TURFs seem generally to have resulted historically in villages or districts getting reasonable access to adjacent fishing grounds. Furthermore these systems have proven flexible in the past, as discussed above, so that changes could be made in TURF boundaries or ownership to accommodate changing needs. This is not to suggest that warfare and power politics have never resulted in departures from equitability in the allocation of TURFs, but to my knowledge this has not generally been a serious problem at least in recent times.

3. Does the TURF facilitate sound economic management of the fishery?

It is often stated that "overcapitalization, a form of economic waste inevitably arises in a fishery to which there is unlimited entry" (Marr, 1976, p. 2). In the absence of limited entry in a capitalist economy fishermen crowd onto the fishing grounds, investing in boats, gas and gear (often paid for in USATPI with precious foreign exchange) to catch the fish that far fewer fishermen could have caught with a much lower expenditure of money and effort.

Maximizing profits may not always be an option which island governments choose, however. Government policy in Southeast Asian countries, for example, increasingly favors employment over economic efficiency in the artisanal sector. One cannot maximize for both where unemployment is high and natural resources are limited relative to demand. Pacific Island governments do not all seem to have clearly worked out their priorities in this regard yet.

TURF owners who exclude others from fully-exploited fishing grounds help to prevent overinvestment and resource depletion. On the other hand, TURF owners who exclude others from underexploited fishing grounds reduce the economic yield. An example of this problem and suggestions for responding to it will be the subject of a later section of this report.

TURFs work against maximizing employment in the short term. But, in the absence of TURFs or some other form of limitation on effort, resource depletion may limit employment much more severely in the longer term.

4. Is the TURF still in operation?

TURFs continue to play a major role in some island cultures (e.g. Yap, Palau, the outer Caroline Islands), a diminished but not insignificant role in others (e.g. Truk, Samoa) and have lapsed in others (e.g. the Marianas, Ponape, Kosrae).

Where TURFs are an impediment to the full exploitation of marine resources it would be politically unacceptable to abolish them if they retain strong community support. Other means of solving the problem must be sought (see below).

Where TURFs are an impediment to full exploitation but are weakly held, the fisheries manager may, in consultation with TURF owners, try to; 1. strengthen but modify them so that they facilitate fuller exploitation, or 2. hasten their demise. In my opinion the latter option will rarely be justified in any of the USATPI, at least in the near future.

3.2. THE ROLES OF TURFs IN CONTEMPORARY RESOURCE MANAGEMENT

Incorporating traditional resource management in contemporary resource management programs is receiving growing attention in developing countries. But it is important not to underestimate the difficulties. These customs evolved in subsistence economies. Some of their features are not always consistent with market economies towards which Pacific island nations are in various stages of transition.

3.2.1. Pressures from Outsiders on TURFs

Perhaps the single most widespread problem in Oceania faced by those charged with fisheries development in areas where TURFs are found concerns the use of tenured fishing grounds by commercial fishermen to obtain the bait fish necessary to support offshore pole fisheries for tuna. For example, the crew of a Korean tuna boat licensed to operate in Palauan waters relied for bait on schools of small fishes netted in tenured lagoon waters. Whenever they sought bait fish they had to land and ask permission to fish. The formal presentation and granting of such requested takes considerable time and ceremony in Palau, as elsewhere in the Pacific. The tuna fishermen were so hampered by this problem that they finally left and valuable resources were left unharvested as a consequence (Johannes, 1981a). Tuna are perhaps the single most important renewable marine resource for Pacific island nations and such problems must not remain unresolved.

One response, has been to arrange some form of royalties paid to the TURF owners for bait caught on their fishing grounds. When this was tried in Papua New Guinea unforeseen problems arose. Arguments developed over just where the traditional TURF boundaries lay. This may not be a major problem in USATPI because boundaries seem generally to be pretty well known and accepted. But a second problem also developed, which might also emerge in USATPI. Just who had the right to share in the royalties became a very contentious issue because of the increasing mobility of the villagers and the growing number of intervillage marriages. In one such case in Papua New Guinea the royalties derived from bait fishing were directed by the court to be held in trust until the disputants settled their differences (Johannes, 1982). I do not know the final outcome. In Fiji, where traditional sea rights have been legally recognised since 1923, established procedures exist for paying cash recompense where fishing rights are adversely affected by foreshore reclamation, dredging, resort development etc. (e.g. Iwakiri, 1983).

When the influx of outsiders reaches a certain point it becomes impractical to defend TURFs and they lapse. For example, in Koror Municipality, the seat of Palau's district center, migrants from outer villages and foreigners converge, overwhelming the traditional order with new economic and social pressures. Immigrants from other districts greatly outnumber traditional residents in Koror and it is close to impossible to determine (or even define) which fishermen are true residents*. In consequence traditional fishing rights are no longer exercised.

The disappearance of fishing tenure in the vicinity of district centers may be inevitable in Oceania. It has already occurred in many places. It is perhaps even desirable insofar as some portions of the coastline must often be set aside for receiving domestic and industrial wastes on one hand and visitors seeking recreational fishing on the other. Both are often incompatible with good fishing. But if they are confined largely to waters around district centers, local deterioration in fishing conditions is perhaps not too large a price to pay.

3.2.2. TURFs Within TURFs

Within a fishing ground associated with a single village or district, fishing rights are sometimes subdivided. The rights to use certain fishing techniques, to fish in certain areas or to catch or consume certain species have been owned, for example, by particular individuals, families of clans (e.g. Yap, Palau (formerly), Ulithi, Etal, American Samoa). I have little personal experience which such systems in USATPI, but I believe that my observations in Papua New Guinea have some relevance.

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* An anonymous reviewer points out correctly that since lineages often possess TURFS, immigrants of the appropriate lineages will automatically possess fishing rights, and that other immigrants are sometimes granted "secondary" use rights. Nevertheless this system has broken down in some district centers such as Koror.

Traditionally such rights could be employed in a flexible manner so that those without formal rights to a fishing area or technique could obtain access upon request. (Often the most highly valued right of property in Oceania has been the right to give it away (e.g. Sahlins, 1974)). But problems may develop when villagers begin to channel their fish into a cash economy. Just as disputes *between* villages increase when cash is involved, so do disputes *within* such villages. As one Papua New Guinean testified in a court case concerning intravillage fishing rights, "Before in customary times we had no trouble..... But when trochus became a business the disputes over the controllers of the reef started."

In Papua New Guinea such disputes have sometimes dragged on for years. Local councils, now often divided among themselves on the issue, find it difficult to come to terms with such problems. Government intervention is sought. But the Government is hampered by conflicting village testimony and the absence of any written records of who owns what.

Fine subdivisions of fishing rights appear in general not to serve conservation functions of overriding importance. Where they are reduced or absent the potential for village disputes - especially in the context of developing cash economies based on fishing - is lessened. Those responsible for fisheries development in USATPI should keep this in mind when targetting development projects. The scope for internal village friction appears great. for example, in some of the outer Caroline Islands where fine internal subdivisions of TURFs exist and where, according to the first Federal States of Micronesia Development Plan, efforts will be made to develop commercial fishing for export to the district centers.

3.2.3. TURFs and Mobile Stocks

Limited entry systems, including TURFs, do not facilitate the conservation of stocks which move beyond the system boundary. For example some species move through different tenured fishing grounds during their spawning migrations or feeding movements. Since fishermen cannot pursue migrating fish beyond the boundaries of their tenured fishing grounds they will not invest in the gear necessary to exploit them adequately.

In 1972, in an unpublished fisheries "progress report", fisheries biologist R. Powell described such a problem on Truk. When he asked fishermen why they did not buy nets to catch abundant mackerel which travelled in schools in the lagoon, he was told that the ownership of fishing grounds prevented fishermen from exercising sufficient mobility to pursue the schools.

Powell stated, "They say that every shoal of fish which schools in close to a village is claimed as the property of that village. This is not a matter of isolated cases but is widely recognized in all islands in the lagoon.

"As a cultural problem in its simplest form, it is one where a community regards fish in front of their village as a natural resource. They can harvest a few as, and when they need with inexpensive fishing gear. The fish are referred to humorously as "money in the bank."

"From the point of view of the tense administrator charged with making great changes and bringing a monied economy by fisheries to backward people who have not yet been motivated to develop a commercial fishery, such schools of fish are an untapped and wasted resource.

"It would take a brave (or stupid) man to attempt to harvest such fish from in front of any island village other than (that of) his own clan, without consulting the chief first. Anyone who does attempt this will bring a Pacific wide problem to a head. An administrator working with an Attorney would be forced into making a decision which will be a definite confliction of two cultures."

The "confliction" Powell refers to here is that between the western tradition of "freedom of the seas" and the Pacific Island tradition of ownership of fishing rights, and between two different philosophies of marine resource management. Powell's frustration has since been felt by "tense" fisheries managers in various other parts of Oceania.

One possible solution is to encourage representatives of different TURFs to work out cooperative arrangements - for example, to purchase jointly a single net to be used cooperatively to harvest the migrating fishes, with portions of the catch, or equivalent cash payments going to owners of each TURF.

3.2.4. TURFs and Aquaculture

Almost ten years ago Johnston first raised the issue of the relationship between property rights arrangements and the nature of aquacultural developments (Johnston, 1977). Aquaculture is held by its proponents to be an important potential source of food and revenue in USATPI. Mangroves are the most common site for aquaculture development in the tropics and mangroves form portions of TURFs in various USATPI. Of what significance are TURFs in relation to aquaculture development?

Unfortunately Johnston's deliberations were, of necessity, theoretical, because no one had studied the problem in the field. As far as I am aware, no one has done so yet in Polynesia or Micronesia. This seems unfortunate; Johnston makes a very good general case for the importance of property rights in determining the nature and degree of success of aquaculture. He points out, for example, that "despite its efficiency, the salmon trap was outlawed in Alaska years ago to avoid control of the industry by the few firms who held strong property rights through ownership of the traps." One can easily imagine similar scenarios in connection with a subdivided TURF where one clan or family happens to own the fishing rights to the best location for an aquaculture development.

On the other hand, as Aristotle said, "that which is owned by the greatest number has the last care bestowed upon it." Aquaculture projects in which the proceeds are the property of a limited number of individuals may be pursued with greater vigor than projects where the access rights are spread over a large community.

I don't know enough about this subject to make any judgements concerning the merits of different TURF arrangements in the context of aquaculture. But I do believe, like Johnston, that the subject is important and deserving of serious study in connection with the USATPI. In particular I recommend a study of what role institutional arrangements such as TURFs have played in the success or failure of aquaculture projects in the Pacific Islands and Southeast Asia. The study should not be limited to the USATPI because there are probably not enough cases to study there as yet in order to produce useful general conclusions.

3.2.5. Alternative to TURFS

In the preceding few pages I have shown why TURFs are not an unmixed blessing in societies undergoing the transition from subsistence to cash economies. Because of the problems TURFs create, some efforts have been made to weaken or invalidate them. In Palau, for example, a bill was introduced in the legislature in 1976 that would permit "all residents of Palau to fish in any waters of the Palau Islands without the incumbrances of traditional right and ownership concerning reef and marine areas." (It failed to pass).

Such efforts are understandable, but I do not believe they are justified, except, possibly, in some cases where TURFs are finely subdivided. Fishing grounds will almost certainly be chronically abused if they are thrown open to all. History provides innumerable examples. Furthermore, any legislation which weakens marine tenure laws also reduces the ability of the owners to police these resources - something they do voluntarily if their rights are secure. Such legislation would therefore increase the government's regulatory responsibilities and place serious additional burdens on already understaffed and underfunded fisheries departments. The government would thus be disposing of services it got for free and assuming expensive new responsibilities it was ill-equipped to handle.

Consider, in the light of western experience, what will probably happen if reef and lagoon tenure laws are invalidated in the USATPI. Fish catches (and profits where there are commercial fisheries) will dwindle as overfishing proceeds. In an attempt to reverse this trend the government will erect a complicated array of regulations - closed seasons, closed areas, size limits, gear restrictions, licenses etc. It will be the only course open other than to invent a whole new system of limited entry to replace the abandoned system or to ignore the problem altogether. But it is an approach which has repeatedly proven both expensive and ineffective in the West. It will prove even less effective in the USATPI for at least five reasons.

1. There are far more species to deal with in the tropics. Thus more regulations and more enforcement would be required to pursue the same objectives.

2. Biologists know much less about these species than they do about temperate marine food fishes and are thus poorly equipped to make useful decisions concerning their conservation. Furthermore, since the catch often does not go through a central market, catch data, which are essential to sound scientific management, are very difficult to obtain. They are, in fact, impossible to obtain at a cost commensurate with the economic gains achieved in small scale island fisheries, except possibly in the case of a very few high-value export species (e.g. lobsters).

3. There are far more boats and far more fishermen to regulate per unit of catch than in Western commercial fisheries.

4. Government enforcement of environmental laws is notoriously lax in most USATPI, and will be further impeded by fishermen who, initially at least, will resent the loss of their TURFs and the imposition of strange new laws.

5. USATPI have far less money per capita than most Western countries to try to cope with these problems.

In short, Western countries are quite unable to manage multi-species tropical reef fisheries on an efficient scientific basis and it will be decades, if ever, before they are able to do so. Of necessity, in the meantime, management prescriptions are based largely on intuitions and good intentions. As a consequence our failures are legion, our successes rare. Traditional Pacific island management customs take on added appeal when we consider the West's dismal record.

If these arguments are not sufficient to persuade the reader that fisheries managers should generally work with TURFs, not against them, then let me reiterate a fact of life in many areas which makes the previous arguments unnecessary. Whereas attempts to invalidate TURFs may sometimes be greeted with approval commercial interests, they will create resentment within island communities on a scale that will often make such moves politically impossible in a democracy. In areas where TURFs have disappeared in Oceania and the causes documented, I know of only one (Manus, Papua New Guinea) where undemocratic colonial governments of a bygone age were not responsible (except in areas around district centers, as described above).

Studies of TURFs and their roles in contemporary fisheries management are in their infancy. If the problems seem complicated now to the readers of this report, this is probably only a foretaste. The ongoing transition from subsistence to cash economies in the USATPI will create increasing difficulties in connection with marine resource management in general and TURFs in particular. Here I have outlined some of the main problems that have come to light so far, but this report falls far short of a comprehensive guideline for management of TURFs in the USATPI. No one has sufficient experience to write such guidelines.

3.2.6. The Subsistence - Cash Continuum

The USATPI and their constituent communities are situated at various positions along a continuum between a total cash economy and a total subsistence economy. Prescriptions for management of marine resources (and most other things) must differ depending upon the location of a particular society along that continuum.

Traditional authority remains relatively strong in the areas lying closest to the subsistence-economy end of the spectrum. An event occurring in the outer Caroline Islands provides an illustration. Turtles at Ulithi Atoll belong to some of the high lineages on the island of Mogmog. Neither turtles nor their eggs may be taken without the consent of the appropriate chiefs. In 1974 a Mogmog chief discovered the remains of a butchered turtle on a beach frequented by the people of Falalop. The Mogmog chiefs angrily issued an edict, "No one on Falalop may touch the sea water for three weeks; do not use the sea for cooking; do not catch any fish or anything from the sea; do not use the sea for 'benjo' (toilet); do not swim in the sea; do not use, travel on or under the sea within or outside the lagoon in the vicinity of Ulithi Atoll; there is nothing in the sea which you can eat."

Failure to obey the order could have resulted in the destruction of personal possessions including crops and houses. Sixty traditional lava lavas (traditional skirts woven from vegetable fibers) were demanded in atonement and subsequently presented, along with abject apologies, to the offended Mogmog chiefs. This proscription on any use of the sea applied even to U.S. government employees on the atoll, Peace Corps personnel, and a Jesuit missionary. Other government officials were warned by radio to stay away for the duration of the atonement. Never are U.S. or former Trust Territory conservation laws accorded such obeisance.

In Palau one comment I often heard in the remoter villages was, "We're not afraid of the courts, but we're scared of Palauan custom (laws). When you are punished Palauan style you are really punished!"

Thus, where traditional authority is still strong and the individuals in whom that authority is invested are concerned about maintaining their natural resources the fisheries manager has a strong (and inexpensive) ally.

Where such authority is faltering, one of the causes has been the gradual government assumption of the responsibilities of traditional leaders. The following statement by Wass (1982, p. 81) concerns American Samoa, but it applies generally throughout the USATPI: "Management regulations instituted on the village level are much more effective than those of the territorial or federal governments because they are promulgated within the cultural context by traditional leaders and, consequently, are more likely to receive the approval and fealty of the villagers. "

"Current management efforts by village councils are not as extensive as in the past. Councils should be encouraged to take a more active role in future management schemes as well as traditional religious beliefs and resource preservation for village use. A fisheries manager armed with...some tentative management recommendations as a basis for discussion should meet with the councils and solicit their opinion regarding management objectives and the means for their achievement. ..... *Much or all of the enforcement responsibility would be assumed by the village if the councils firmly believed that the management strategy was beneficial*," (emphasis added).

Where traditional authority over resource use has declined beyond the probable point of no return, e.g. in the vicinity of most towns, fisheries cooperatives are a possible means of using non-traditional authority, but authority, nevertheless, that still resides at the local level, to pursue management objectives.

The Japanese took this route, gradually transferring TURFs from traditional village leaders to village-based cooperatives. Ruddle (1985, p. 161) states with reference to this system, "it is refreshing to also have in the Asia-Pacific region the example of Japanese nearshore fisheries, which, although by no means perfect in their adminstration and operation, stand in complete contrast to the dismal litany characteristic of most other countries in the Western Pacific."

This approach is no panacea however. Many fisheries cooperatives in various developing countries, including some in USATPI, have failed. The subject of cooperatives is complex. Space (and my limited expertise) prevents me from exploring it in detail here. But two caveats should be mentioned.

Ruddle (1985) stresses that the Japanese system of nearshore TURFs cannot be assumed to be transferrable to other socio-economic contexts. (But the principle behind it - that of allowing traditional TURF systems to evolve to meet changing circumstances, rather than replacing them with alien (and not very successful) arrangements based on Western traditions - deserves to be tried).

Finally, a point made by Alexander (1980, p. 9) deserves repeating, namely: "It is easy to romanticize these social arrangements, to see peasant villagers as possessing a unique cooperative mentality. This is mistaken. Reciprocal labor relations persist because they perform vital economic functions, because debts are calculated in time if not in money, and because the institutions are maintained not only by moral norms but by the abrasive force of envy and gossip. Attempts to introduce cooperatives which do not recognize this are doomed to failure."

4. CONCLUSIONS

A continent dweller is liable to assume that the environmental and economic conditions and the cultures of the people that populate the USATPI are homogeneous and that their resource management problems are, accordingly, fairly standard and therefore amenable to standardized solutions. The foregoing discussion has hopefully demonstrated the errors in this assumption.

It has been argued above that traditional use rights in fisheries should be integrated with contemporary systems of marine resource use in the USATPI where they are found, namely the Marshall Islands, American Samoa and the Caroline Islands excepting Ponape and Kosrae. But whereas available information is sufficient to document the general features of TURFs in these islands it is not sufficient to enable use to generate specific practical island-by-island recommendations concerning how, precisely, this should be done.

Resource management problems in USATPI are not only very complex at any one place or time, they also vary greatly with space and time, and Western resource managers are simply not in a position to solve them unilaterally. The biological and socio-economic knowledge bases are much too slim.

There are two general responses to this problem; neither are novel: 1. Obtain more information. 2. Support and encourage greater local involvement in marine resource management.

4.1. INFORMATION NEEDS

The management of biological resources is too important to be left entirely to biologists. (In case readers think they detect a professional bias here, it should be pointed out that the writer is a biologist). Arguments have been advanced above for the importance of social science research in this context. There has been almost no direct input from social scientists concerning marine resource management in the USATPI. This should be remedied.

More needs to be known about the current status of TURFs in the USATPI, especially American Samoa, Truk and the outer Caroline Islands. (For a list of specific questions that should be addressed, see Appendix I). The "right" kinds of individuals to carry out such studies could be biologists, geographers or anthropologists, but there is probably a greater likelihood of finding such individuals among the latter two groups.

A study should be made of the implications of TURFs for aquaculture development in the islands. It should involve both a review of the literature pertaining to other areas (Southeast Asia in particular) and field research in the USATPI.

One of the main objectives of the field research should be to determine whether past failures in aquaculture efforts can be traced in any significant degree to problems associated with traditional tenure systems.

Unless things have improved recently, the social dimensions of successful aquaculture have received no explicit attention from researchers in the USATPI.

Undoubtedly other writers contributing to the report of which this manuscript forms a portion will call for better education of marine resource managers in USATPI. A thorough examination of TURFs and their implications for management should form a part of that training.

Legislation has been introduced in various Pacific island countries to protect traditional fishing rights. This is a laudable objective. But the effect of such legislation, unless very carefully conceived, is to freeze what traditionally were flexible systems of resource management and allocation. In the past, fishing boundaries and associated use rights changed as populations shifted or political or economic conditions changed. It would be valuable to the USATPI to have available for their consideration a study of existing relevant legislation throughout Oceania and its advantages and shortcomings as perceived by fishermen and marine resource managers. (Fiji has considerable experience in this area). At present I do not believe such a study exists.

Traditional fishing boundaries and the nature of the associated TURFs should be recorded for all USATPI. However, because resources within island fishing grounds are becoming increasingly valuable as populations increase and export markets get functionally closer due to improved tranportation, the value of TURFs is increasing. Under the circumstances it is not surprising to find that villagers will invent "traditional" fishing rights. Information obtained from villagers on their fishing rights and customs is thus likely to be more reliable if it is elicited prior to the introduction of plans for commercial fisheries development in their waters. In other words, it should be gathered without delay.

4.2. ENCOURAGING COMMUNITY INVOLVEMENT IN MANAGEMENT

Efforts to reconcile government marine resource programs with TURFs (as well as with other local customs and aspirations) can only benefit from improved communication between resource users and resource managers. Lack of such communication in the past has resulted in some monumentally misguided government initiatives in the coastal waters of Oceania (e.g. Johannes, 1981b).

The current shift from expatriate to indigenous government resource managers will not necessarily always alleviate the problem. Indigenous resource managers have Western educations. They are liable, in my experience, to have absorbed Western ideas and prejudices that render some of them almost as insensitive as many expatriates to their brethren in the villages.

The typical fisheries manager in Oceania is much too harassed and his responsibilities too numerous to enable him to spend much of his time in "extension" activities. I believe, therefore, that USATPIs should employ carefully chosen individuals whose sole responsibility is to serve as liaison between fishing communities and the government. Often such work would require living in fishing communities for weeks or months at a time (see Johannes (1981b) for discussion of some of the practical aspects of such involvements). Ways should be explored with village chiefs and other traditional resource managers to develop or modify TURFs to meet modern needs.

Such activities can only be successful if villagers are approached in a patient, relaxed manner by someone they have known long enough, preferably within their villages, to trust and feel at ease with. It is hard to convey to someone who has never been involved in such situations the singular importance of this seemingly bland recommendation.

4.3. THE BROADER CONTEXT

Integrating TURFs with modern fisheries management is but one subset of a host of challenges to those charged with developing and managing marine resources in USATPI. Other problems include the following:

-economies of scale are not available, making competition with larger-scale, higher-technology fisheries very difficult. For example, imported canned mackerel, which consumed in large and increasing quantities in many tropical Pacific Islands, often costs less than fish caught within sight of the local market.

-maintenance of freezers, motors and other gear is expensive, sometimes beyond the skills of those who operate them, and plagued by high costs and inadequate supplies of replacement parts.

-many small scale fishermen are unwilling to engage in capital risk-taking in order to achieve higher profits, preferring the comparative security and familiarity of simple, inexpensive methods even if they yield only subsistence levels of income. Those few fishermen who are willing and can afford to use improved technology may come to dominate the fishery; the standard of living of the rest may thus stagnate or decline.

-fishing customs are intimately enmeshed in local social and religious practices. This creates both opportunities for and impediments to management that have often been overlooked by western-trained fisheries managers. TURFs are just one example.

A number of writers, including the author, have suggested in the past that we need studies of the causes for the failure of many artisanal fisheries development and management programs. Today we have a pretty good idea of what those general causes are. More valuable now, I believe, would be the identification and evaluation of programs that have succeeded. Discovering just how anyone manages to succeed - if indeed anyone has for more than a year or two - in suh a demanding and complex task would be a very valuable undertaking. We might discover that charisma, empathy and patience count for as much as or more than scientific expertise.

A more detailed discussion of the broader aspects of artisanal fisheries development and management is beyond the scope of this report. The reader is referred to Lawson (1977, p. 198), Emmerson (1980) and Kearney (198).

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APPENDIX 1.

This is taken from recommendations made by the UNESCO Working Group on Traditional Fishing Rights Boundaries and Associated Resource Use and published under the heading, "Results of the Seminar" in Ruddle, K. and R. E. Johannes (eds.) The Traditional Knowledge and Management of Coastal Systems in Asia and the Pacific. UNESCO, Jakarta, 1985, 313 pp.

Information Needs on Traditional Fishing Rights Boundaries and Associated Resource Use

Today, with the advent of commercial development in coastal marine systems controlled by traditional users, there is a need to identify and define traditional boundaries to provide an effective legal basis for traditional activities while accommodating compatible commercial development. The topic of boundaries arises here from the need for guidelines to help facilitate identification and definition of the limit of areas in which traditional rights are exercised.

The "Working Group on Traditional Fishing Rights Boundaries and Associated Resource Use" recognised that its discussions represented only a preliminary step in the direction of resolving difficulties arising in the absence of clear and formally recognised traditional resource rights. It decided to compose a list of questions that should be answered to enable those concerned with the management of coastal marine and estuarine resources to understand the nature of the traditional boundaries and associated traditional use rights.

These questions are presented below together with references to papers published in these proceedings which raise matters related to each question (numbers refer to paper order).

Boundaries:

What indications are there that traditional boundaries exist? (2,3,4,6,9)

What are the purposes of boundaries? (e.g., to protect resources, to allocate resources, to minimise disputes, to manifest a group's cultural identity) (2,4,6)

How are such boundaries defined traditionally and how did they evolve? (4,6)

What criteria are used to locate boundaries (e.g., depth contours, prominent "land" marks, linear extension seaward of land boundaries) and to what point seaward do they extend? (2,3,4,5,6)

Are the boundaries claimed by a traditional group recognised by other such groups in the vicinity? (6,9)

Have traditional boundaries changed according to changed needs, altered perceptions of contained resources, geomorphological changes, usurpation or conquest? (3,5)

Are there internal subdivisions within areas defined by boundaries? (3,4,5)

Resources within traditional boundaries:

What has been the traditional significance of the contained resources and what is their significance to traditional users today? (3,4,5,9)

What is the significance of the contained resources to outsiders? (3,4,5)

What is the nature of the rights to resources within the bounded area? (Not only subsections of a bounded area, but also species, harvesting techniques, or improvements -- e.g., fish traps -- may be "owned" by subgroups or individuals within a community) (2,3,4,6)

Can traditional rights be transferred (e.g., traded, sold, given, loaned, rented, bequeathed)? If so, under what conditions? (2,3,4, 6)

What is the relationship between traditional rights and legally defined rights? (2,3,4,5,6)

Boundary permeability:

How permeable are traditional rights boundaries? (5,6)

To what extent is provision made for innocent passage across traditional boundaries and can adjustments be made to allow for physical (e.g., geomorphological) changes which may affect access? (2)

Boundary and Resource Control:

Who controls traditional resource use within traditional boundaries? (2,3,4,5,6)

What were and are means of enforcement of the integrity of traditional boundaries? (2,4,6)

What were and are traditional methods of boundary dispute resolution and how effective are these measures now? (2,4)

What are the provisions, if any, for compensation where boundaries or rights are transgressed? (3,9)

Adaptation:

How robust is the traditional system in its present cultural context? (4,6,9)

How robust is the traditional system in relation to commercial and cultural intrusions? (4,5,9)

What might be the consequences of boundary formalisation (e.g., legal definition and recognition)?

An investigator should seek to understand the relationships of boundaries not only to traditional rights, but also to resource conservation and to the social structure of the relevant traditional communities.

It is especially important, although often difficult, to define the true nature of traditional marine and estuarine resource rights. For example, are these rights to own or just to use? -- to specific resources or to all resources within the defined area?

Another difficult but important question is, to what extent is outside intervention warranted (e.g., through boundary formalisation) to ensure effective use of the contained resources? Wherever appropriate efforts should first be made to support existing traditional conservation measures and traditional procedures for boundary dispute resolution. Often, only those types of disputes beyond the judicial abilities of local leaders or outside their traditional framework need to be brought to the attention of governments for adjudication. The more responsibility for control of resource use that can be left to the traditional users, the fewer the social, political, legal and conservation-related problems that must be addressed by governments. Moreover, the fossilisation of tradition through explicit, detailed legal definition may weaken the adaptive flexibility of a traditional system.

Background Paper No. 2

AQUACULTURE AND MARICULTURE DEVELOPMENT IN THE U.S. PACIFIC INSULAR AREAS

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

ABSTRACT

The climate and traditions of the tropical Pacific islands are well suited to many types of aquacultural development although the economic potential for such development remains largely unrealized. The U.S. Pacific insular areas encompass a wide geographic range which consists of an expanse of ocean dotted with small land masses. The island cultures of the region are quite diverse and differ greatly in the levels of technological and economic development attained or desired. The ocean's resources are important in all of the Pacific island cultures. Although fishing is the primary means of obtaining food from the sea for these people, there is a high level of interest in the development of aquaculture within the region. This method of food production is appealing as a result of the traditional reliances of the islands on the resources of the nearshore waters. Most of the island groups have operated experimental or pilot-scale culture operations of one form or another. There are indications that some forms of traditional aquaculture existed in Yap, Pingelap (Pohnpei district), Kapingamarangi, and Kosrae, but these traditions were not well developed in the region in general. The island nations of Kirabati and Nauru also practiced traditional methods of fish culture. Modern interests in aquaculture derive from the desire to increase income and from concern over the decreasing fish catches in many areas. Species which have been identified as having particular potential for aquacultural development in the region include freshwater prawns, marine shrimp, giant clams, pearl oysters, rabbitfishes, milkfish, mullets, tilapia, and economic seaweeds. The major constraints to aquaculture development include the limited land areas, the lack of local sources of juveniles and post-larvae, restrictive shipping costs, the lack of aquaculture extension programs and marine advisory services, the lack of regional planning and coordination, the limited database available concerning aquatic and marine species of the region, the lack of information on aquaculture economics, and the lack of sustained funding for relevant aquaculture research programs.

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INTRODUCTION

The islands of Micronesia have an underutilised potential for aquaculture. The warm, stable climate of this region provides conditions capable of sustaining high rates of aquatic productivity. This is evidenced by the fact that the nearshore marine ecosystems characteristic of this area are among the most productive in the world. The realization of this potential, however, presents some interesting problems since the cultural settings and the levels of technological development vary greatly between island groups. Special problems in relation to markets, transportation costs, and isolation have all contributed to the lack of major aquacultural development at present.

All of the islands share the problems associated with a limited land area and a strong traditional reliance on marine resources (Johannes, 1977, 1978). As a result of their long and intimate association with the sea, the people of the Pacific Islands are generally quite knowledgeable about marine life, and a good number possess an amazing knowledge of reef fishes and other marine organisms of importance to their daily lives. The extent of this knowledge has only recently been appreciated by the scientific community (Johannes, 1981) and has yet to be fully revealed. The tasks of obtaining food from the surrounding oceans have traditionally focused on fishing, the capture of terrestrial crabs, and on the gleaning of shallow-water benthic invertebrates from the surrounding reefs. Today, the island cultures of Micronesia and American Samoa range from the highly Westernized and technologically sophisticated society of Guam to the essentially non-moneyed economies of the outer Caroline Islands. The technical capabilities of specific sites are major determinants of the appropriateness of the technologies targeted for development. Other sociological factors, such as the nature and strengths of the extended family systems, also play major roles in the identification of technologies appropriate for development within the region.

It is the purpose of this paper to examine and assess the potential for development of a variety of aquacultural schemes for the U.S.-affiliated islands of the tropical Pacific including the island groups of American Samoa, Belau, the Federated States of Micronesia (Truk, Yap, Pohnpei, and Kosrae), Guam, the Marshall Islands, and the Northern Mariana Islands. I hope to identify particularly promising opportunities for aquaculture development in these Pacific islands, to examine the constraints which have largely prevented such development, and to recommend strategies for overcoming these constraints.

ENVIRONMENTAL SETTING

The geographic area known as Micronesia covers an area larger than the continental United States but possesses a combined land mass smaller than the state of Rhode Island. These tropical islands of the western Pacific are American protectorates, along with American Samoa in Polynesia, and their warm nearshore waters are analogous to oases in a vast, oceanic desert. The marine ecosystems of Micronesia and Samoa are among the most diverse in the world and are highly productive in spite of their extremely low nutrient levels.

The islands may be roughly divided into two major categories 1) high islands of volcanic origin and 2) low islands, or atolls, of biogenic origin. Habitats associated with high islands include fringing reefs, barrier reefs, lagoons, mangrove swamps, bays, rivers, and small lakes (freshwater, brackish, and marine), whereas atolls are limited to lagoon and outer reef habitats. Nutrient inputs are higher around high islands as a result of periodic run-off from the land during heavy rains (see Birkeland, 1984) . The input of nutrients can have rather profound effects on the nearshore marine communities such as evidenced, for example, by the sporadic outbreaks of the crown-of-thorns starfish which occur primarily in association with high islands in this region (Marsh and Tsuda, 1973). In addition, some marine organisms are found only near high islands or are rare near low islands (see

Birkeland, 1984). Presumably, this is a result of the lower nutrient availability near atolls.

Some islands, such as those of the Mariana archipelago, are subject to the disruptive, and unpredictable, influences of tropical typhoons. These meterological events are characterized by high winds, at times in excess of 200 miles per hour, and destructive waves. These storms are a fact of life in many areas and such events impact negatively on the development of aquaculture as coastal structures may be destroyed, ponds may flood, and electrical power may be disrupted for days.

The general environmental characteristics of the region affect the strategies for development of tropical aquaculture in a variety of ways. For example, the shortage of land area often prohibits the large-scale development of pond aquaculture. The intensity and frequency of tropical storms makes the use of pen or cage aquaculture technologies impossible except in protected lagoons and large bays. The generally low levels of dissolved nutrients and the subsequently low standing crops of phytoplankton greatly reduce the feasibility of culturing such filter feeding marine organisms as oysters. Exceptions occur in areas, such as bays or lagoons, which are enclosed and subsequently have retention times which allow greater phytoplankton productivity (Birkeland, 1984). Aquaculture technologies will be, by necessity, modified in order to meet site-specific requirements.

ISLAND TRADITIONS RELATIVE TO AQUACULTURE DEVELOPMENT

The people of the Pacific are fishermen par excellence and employ a variety of fishing techniques including trolling, fish traps, poisons, and spears (Lewis, 1967; Johannes, 1981; Hunter-Anderson, 1981; Sudo, 1984, for examples). Ocean fishes are held in high esteem and, in general, they are of greater value than freshwater fishes. An example for Guam is cited in the work of Carano and Sanchez (1964). Some exceptions occur, however, such as the desirability of freshwater eels to the people of Kosrae (A. Edward, personal communication, December 1985). On some islands, certain species of marine fishes are particularly favored, and the distribution of the catch of these fishes may be limited to, or controlled by, the village chief. For example, the distribution of grouper (Serranidae) catches in the Caroline Islands is limited to the village chief; other such cases concerning the distribution of fishes and turtles are cited by Sudo (1984).

In spite of the importance of marine fishes to the daily lives of the island people, there are few documented traditions of aquaculture in the region. Evidence exists, however, that there was some degree of fish culture practiced in several areas of Micronesia, and stone structures used as fish ponds have been reported from a number of island groups. There are such structures at Yap which reportedly were used either for fish culture or, at least, for the short-term holding of fishes (M. Falanruw, personal communication, June 1985). Also, Ahser Edward reported (personal communication, August 1985) that fish pens constructed of stone were used in the lagoon of Pingelap (Pohnpei district) to hold fishes which had been caught and then transported to the pens in loosely woven baskets. Only one of the three fish pens in the Pingelap lagoon is still operational, and these fishes are fed daily with breadfruit and coconut meat. A stone fish pond, 20 meters in diameter, has also been reported to exist near the entrance to the lagoon of Kapingamarangi (Leach and Ward, 1981). In addition, stone structures found on Kosrae were reportedly used to hold turtles which were used by priests of a particular (Nosrunsrap) cult in special ceremonies (Cordy, 1983). Similar stone pens for holding turtles also existed in Yap (R. Hunter-Anderson, personal communication, December 1985).

The nearby island nations of Kiribati and Nauru also have traditions of fish cultivation. Both of these cases involve the culture of milkfish Chanos chanos. In Kirabati, especially in the southern islands, milkfish are harvested from a number of naturally occurring ponds. These fish apparently appear in the ponds without being artificially stocked and they are not fed by the pond owners (K. Knudson, personal communication, December 1985). However, on Nauru the milkfish were stocked, fed and reared in an inland lagoon which was partitioned into a number of smaller, individually owned ponds. The Nauruans harvested the fish primarily for consumption on special occasions but were also harvested for use as bait (Petit-Skinner, 1981).

The elaborate and diverse traditions of fish cultivation as reported to have existed in the Hawaiian Islands (Kikuchi, 1976; Summers, 1964) apparently did not develop in this region.

In addition, shellfish, particularly pearl oysters, have been important items of commerce for centuries in some areas within the region. The pearl shell industry had a major impact on some islands as a result of the activities of the foreign traders and fishermen drawn to the islands to exploit the stocks of the Golden Lipped (*Pinctada maxima*) and the, smaller, Black Lipped (*P. margaritifera*) Pearl Shell (Oliver, 1962). As stocks of pearl oysters were depleted, the topshell, *Trochus niloticus*, came to be used as a source of shell for buttons and other items (Oliver, 1962; Nishi, 1968) and continues today to be a major item of export of several island groups. In Micronesia, the topshell occurs naturally only in the waters of Belau, but this species has been introduced to several other island groups in the region.

The level of interest in aquaculture in the region today is quite high, and most island groups have done preliminary work to determine the feasibility of culturing a number of marine and freshwater species of fish and shellfish.

RECENT HISTORY OF AQUACULTURE RESEARCH AND DEVELOPMENT

Most of the island groups have demonstrated an active interest in the development of aquaculture in their regions. This, in part, reflects the growing interest in aquaculture in the continental United States (Weatherly and Cogger, 1977; Klausner, 1985, for example). A Pacific Islands Mariculture conference (Anon., 1973) was convened some years ago in order to advise the development of aquaculture in the region. The current efforts in this area have been presented in some detail by Uwate et al. (1984) and summarized by Uwate and Kunatuba (1984) for the Pacific islands in general and by FitzGerald and Nelson (1979) and FitzGerald (1982) for Guam. A variety of species have been examined with regard to their potential for aquaculture development in the Pacific islands (Uwate et al., 1984; FitzGerald and Nelson, 1979). Aquaculture in this region has been proposed for a variety of purposes including food production, phycocolloid production, water treatment, and baitfish production. A number of agencies have funded aquaculture research in these areas. The government of Guam has even completed an Aquaculture Development Plan (FitzGerald, 1982) and funded feasibility studies for the operation of a multi-species hatchery (Aquatic Farms, Ltd., 1979).

One internationally funded company (Guam Aqua Research, Inc.) was started on Guam to develop hatchery technologies for marine shrimp. The project was managed by Mr. T. Fujimura and Dr. Michael New, both of whom are well known in international aquaculture circles. The aim of this company apparently was to develop hatchery technologies to be exported to Southeast Asia rather than to supply local needs for post-larvae. This company was rather short lived, but their physical facility, which is quite good, is still intact on Guam. The facility has recently been acquired by the Government of Guam and is under the supervision of the Guam Department of Commerce. Arrangements are currently being negotiated for the use of the facility as a hatchery.

In spite of the long-term interest and previous work, there are few commercially viable aquaculture ventures in the region at present. Several have been developed on Guam which has a relatively large local market and a fairly sophisticated technological base. The species which have been tested for aquacultural development are many (Uwate et al., 1984). Those which have been or are under commercial production in the region are presented in Table 1. Major research efforts are currently underway to develop the cultivation of phycocolloid-bearing seaweeds (Guam, Kosrae, and Pohnpei), freshwater prawns (Guam), giant clams (Belau), rabbitfish (Guam and Belau), and green mussels (Western Samoa). The research activities are being undertaken by several agencies including the University of Guam, the Micronesian Mariculture Demonstration Center at Belau, the College of Micronesia, and the University of Hawaii, as well as the various marine resource and fisheries agencies of the local governments. The Pohnpei government has recently established an aquaculture research laboratory. Aquaculture research and development projects have been funded by various combinations of federal and local funds. Basic research projects in the region have been supported primarily by federal funds, usually with in-kind matching funds provided by the local government. The requirement for matching funds for the first $200,000 of federal funds, however, has recently been waived (Public Law 98-454, Section 601b) for American Samoa, Guam and the Northern Mariana Islands.

SPECIES WITH POTENTIAL FOR AQUACULTURE DEVELOPMENT

A number of species with potential for aquaculture development in the region have been identified, and these are presented below, along with a summary of their characteristics. I have omitted discussion of the possibilities of baitfish culture although this has received considerable attention, especially in American Samoa, since the feasibility of this operation is being tested (Baldwin, n.d., 1974; Kearney and Rivkin, 1981; Lambert and Bryan, 1979; Vergne et al., 1978). Following is a discussion of the factors which contribute to the potential for development of culture systems for selected species, the constraints to this development, and specific technologies which would be appropriate and conducive to such development.

Freshwater Prawns

The culture of the giant freshwater prawn *Macrobrachium rosenbergii* is currently practiced commercially on a small scale on Guam. This species has been examined for aquaculture potential (Blommstein, et al., 1977) and cultured on an experimental scale in Belau. The prawn occurs naturally in the freshwater streams of Belau but not on Guam. The strain which is cultured on Guam was imported from hatchery-reared stock in Hawaii which originated from stock imported from Malaysia. This species is cultivated around the world, since the hatchery techniques for mass production of post-larval stages have been well developed. There is interest in cultivation of this prawn in several islands of Micronesia, including Guam, Belau, Pohnpei, and Yap.

The cultivation of *M. rosenbergii* on Guam has been underway on a small commercial scale for several years. According to the Guam Aquaculture Association, the major factor limiting freshwater prawn production is the availability of post-larvae for stocking the ponds (D. Crisostomo, December, 1985). There is no hatchery on Guam at present, although the need for one has been recognized by everyone involved in the Guam aquaculture industry. The pond operators have been unhappy with the attempts to obtain the post-larvae from commercial hatcheries in Hawaii for several reasons, including the high shipping costs, the unreliability of the supply, excessive mortalities, and the reportedly poor growth performance of these post-larvae in comparison to the post-larvae produced locally in a temporary hatchery established at the Marine Laboratory at the University of Guam. The Micronesian Mariculture Demonstration Center has the facilities and technical capability to operate a hatchery if enough post-larvae were to be purchased by groups from other islands such as Guam.

The growth of *M. rosenbergii* in the ponds of Guam has proven satisfactory (FitzGerald and Nelson, 1979). The water temperatures in the region allow growth all year round and provide conditions well suited to the physiological requirements of this species (Nelson et al., 1977). However, suitable areas for pond construction on Guam are very limited (FitzGerald and Nelson, 1979), as is the case on most of the Pacific islands. Areas suitable for culture are those near a year-round supply of water, accessible to vehicles, with clay soil that will allow pond construction (limestone soils are too permeable), and located on land with a gentle slope. There is also a severely limited supply of freshwater during the dry season. The culture of *Macrobrachium* is limited to areas near the larger drainage basins which have year-round water flow. Areas especially suitable for *Macrobrachium* culture occur on Pohnpei, Belau and Guam. Islands without abundant freshwater supplies have extremely limited potential for freshwater prawn culture.

Although *Macrobrachium rosenbergii* occurs in the streams of Belau (McVey, 1975), it is not found naturally on most other islands of Micronesia. However, several, mostly smaller, endemic species of *Macrobrachium* occur in the freshwater habitats of the region. Among these is another large species, *M. lar*, which is found on Pacific islands from the Ryukyus to Tahiti (Maciolek, 1977). In several areas, work has focused on the development of this species for aquaculture (Villaluz, 1972; Ling and Costello,1977; Maciolek, 1977; Nelson and Kropp, 1985) with the idea that ponds could be stocked with post-larvae and juveniles obtained from the local streams. Villaluz (1972) pointed out several problems with the strategy of stocking ponds from wild-caught juveniles; principal among these was the potential introduction of predators and competitors along with the juvenile and post-larval prawns.

Attempts have been made to develop hatchery techniques for *M. lar* (Atkinson, 1977), but to date there is no source of the post-larvae of this species, so juveniles must be collected from the streams. The physiological requirements of the larval stages of this species are apparently quite different from those of the commonly raised *M. rosenbergii*. The larvae of *M. lar* require higher salinities than *M. rosenbergii*, which is not surprising given the apparent need for long range oceanic dispersal of the larvae of the former species.

Another problem with the culture of M. lar is its highly aggressive nature (Goodwin and Hanson, 1975; Donaldson, 1981). This species was introduced to the streams of Hawaii from Guam and apparently was able to displace an endemic Macrobrachium species (Kubota, 1972). However, in spite of the problems associated with this species, it still may be worthy of attention for cultivation on a subsistence or cottage-scale basis in areas where the cultivation of M. rosenbergii is not feasible.

Marine Shrimp

Marine shrimp of the genus Penaeus also have potential for cultivation in this region, and preliminary culture trials have been conducted on Guam and in American Samoa (L. Eldredge, personal communication, July 1985). The major problem with the cultivation of marine shrimp in this region is that the juveniles are not available, and there are not sufficiently large stocks of shrimp in the shallow nearshore waters to supply a hatchery. Once the technology necessary for maturation and spawning of these shrimp is fully developed, then the potential for the culture of these species will be enhanced. Currently a large project is being considered for development on Saipan which involves a joint effort between investors in Saipan and experienced aquaculture consultants, including Dr. I. C. Liao, from Taiwan (D. Knudson, personal communication, July 1985). If reliable sources of juveniles can be obtained, such as from hatcheries in Taiwan, then the success of such a project is very likely.

One consideration is the nearby market in Japan. However, while it may be possible to cater to this export market, it should be realized that such plans will necessarily involve competition with shrimp producers in the Philippines, Taiwan, and elsewhere in Southeast Asia where labor costs are quite low. In Japan the demand is for _Penaeus japonicus_ whereas in Taiwan and the Philippines the production is primarily of _P. monodon_. Marketing studies are needed in the early stages of regional planning for the development of marine shrimp aquaculture.

Other crustaceans

The only crustacean, other than marine and freshwater shrimp, which may have potential for cultivation in the region is the mangrove crab _Scylla serrata_. This species has been examined for its potential for culture on Guam where natural stocks are very limited (Dickinson, 1977), but no sustained commercial development has been realized. This species has been cultured in Taiwan although Bardach et al. (1972) reported that this was a matter more of harvesting the crabs which entered the ponds incidentally rather than a managed program. There are no available juvenile mangrove crabs for stocking and hence, there is little interest in the cultivation of this species in the region at present.

Rabbitfish (Siganidae)

Several species of siganids are found throughout the Pacific, and these are highly prized food fishes of the island people. Although there is presently no commercial production of siganids in the region, a number of species of rabbitfishes are attractive aquaculture candidates (Lam, 1974; Macintosh, 1982). One of the prime reasons for interest in this group is that they are herbivorous, and, at least in some areas and at certain times of the year, the juveniles can be collected from the reef-flats in large numbers (Kami and Ikehara, 1976). A number of researchers have focused their attention on the development of siganid culture in Micronesia (Tsuda and Bryan, 1973; May et al., 1974; Bryan, 1975; Bryan et al., 1975, Hasse et al., 1977; Tobias, 1976), and similar efforts are currently underway on Guam.

Although siganids are herbivorous, they will readily accept and thrive on commercially available pelletized diets. In nature, siganids feed primarily on fleshy macroalgae (Tsuda and Bryan, 1973; Von Westernhagen, 1973; Lundberg and Lipkin, 1979). They have been reported to occur on the reef flats in such numbers during seasonal recruitment episodes that their preferred algae are decimated to the point that the stocks suffer mortality from starvation. They feed almost constantly in culture and will take a variety of food items including fish and poultry feeds (Von Westernhagen, 1974; Tobias, 1976). Since rabbitfish will accept such a wide variety of items, feed development is not considered to be a major problem. However, diets and feeding schedules need to be developed which will provide optimum conversion and cost efficiencies.

The juveniles may be collected at predictable times from the reef flats of some areas, including Guam. However, the abundance of the juveniles from year to year is extremely variable and ranges from almost negligible to conditions where the reefs are practically denuded of suitable algal food. The availability of stable supplies of juveniles will depend eventually on their mass production in hatcheries. The development of hatchery technologies for these species is underway and several species have already been spawned and reared in captivity (Popper et al., 1973; Von Westernhagen and Rosenthal, 1976; Juario et al., 1984).

Generally, the spawning of rabbitfishes can be induced by hormone (Human Chorionic Gonadotropin) injections (Bryan et al., 1975). The larvae can be reared through their planktonic larval stage on an initial diet of rotifers and brine shrimp nauplii (May et al., 1974). Juveniles were consistently produced on a small scale at the hatchery of the Micronesian Demonstration Center in Belau for several years. However, in order to achieve the mass production of juveniles, hatchery-related mortalities must be reduced.

The culture of siganids can be achieved either in ponds and natural enclosures (as has been demonstrated at the Micronesian Mariculture Demonstration Center at Belau) or in cages (Tobias, 1976; Lichatowitch et al., 1984). They can survive in brackish water as well as in seawater. Further work on the development of grow-out technologies for siganids is needed. Data on feeding rates and environmental conditions in relation to production are much needed. Such work is warranted, since these are a prized fish throughout the region. On Guam, siganids bring a good retail price ($4.47 to $5.24 per kg), and it has been estimated by Myers et al. (1983) that the market demand can not be met by the local fisheries.

Research efforts toward the development of siganid culture are proceeding in several regions outside of Micronesia as well. Notable efforts are being undertaken in the Molucca Islands (B. Wenno, Personal Communication), Fiji (Gundermann et al., 1983) French Polynesia, Tanzania (Bwathondi, 1981), Hong Kong (Tseng and Chan, 1982), Kuwait (Akatsu et al., 1984), and near the Red Sea (Lichatowich et al., 1984; Popper et al., 1973, 1976, and 1979).

Milkfish

Milkfish (*Chanos chanos*) are popular in markets on Guam and in other areas of Micronesia. Milkfish are hardy and can survive and grow under a variety of environmental conditions from seawater to freshwater. Most commonly, they are cultured in brackish water ponds. This species has been successfully cultivated on a commercial scale in several adjacent regions, notably in the Philippines and Taiwan, and milkfish are currently being cultured in ponds on Guam. Milkfish have also been cultured on Nauru (Pitit-Skinner,

1981) and in Kirabati (Crear, 1980). About 20 per cent of the fishes imported to Guam from the Philippines are milkfish (Myers et al., 1983).

Previously, the major problem with cultivating milkfish was the acquisition of a suitable number of juveniles for stocking the ponds. Milkfish fry for stocking were primarily collected from the wild (Villaluz et al., 1982). Around Guam, and many other islands in Micronesia, the milkfish stocks are too small to support a fry fishing industry. Areas in the region with sufficient milkfish stocks, such as in Belau, have not developed milkfish culture since fish in these regions are low priced as a result of their abundance. Recently a company based in Belau was advertising the availability of the fry for export (D. Crisostomo, personal communication, July 1985) but the industry has not developed probably because the labor intensive fry-collection industry would not prove profitable at this time. The exportation of fry from the Philippines, where milkfish aquaculture is well developed, was banned by their government because of the importance of the milkfish industry to their economy (Smith, 1981). Thus, it has been somewhat difficult to obtain fry for use in other areas which have an interest in milkfish cultivation. Recently, however, aquaculturists have been able to spawn pond-reared broodstock. Hatchery techniques are being developed (Duray and Bagarinao, 1984), and it seems that the availability of milkfish fry will dramatically increase in the near future. This should remove the major constraint to development of milkfish culture in this region.

Mullets

Mullet culture has received little attention in the region but these species may have considerable potential for development. Several species of mullet occur in the region, and these include species of the genera *Liza*, *Valamugil*, *Chelon*, and *Neomyxus*. These species have received some attention on Guam, since the juveniles are abundant in shallow waters around the island and it was felt that these fry could be collected and used in small scale aquaculture operations. The culture of mullets was also recommended for a sightly brackish lake on Pulusuk (Truk district) for use when the sea is too rough for fishing (Nelson and Cushing, 1982). Although these fishes readily accept pelletized feed, the limited data available (S. Nelson, unpublished) indicate that most of the local mullet species have growth rates that are slow relative to those, say, of milkfish. However, techniques for induced spawning and grow out of the larger species such as the grey mullet, *Mugil cephalus*, have been well developed (Shehadeh and Nash, 1980) and either the importation of fry or their production in a hatchery would allow the culture of this species.

Mullet culture in the region deserves further consideration. Sources of fry need to be identified as an initial step.

Tilapia

Two species of tilapia, *Oreochromis mossambicus* and *Tilapia zillii*, have been introduced to Micronesia. The former species has been established in wild populations on Guam, Saipan, and Pagan in the Marianas and on Christmas Island in Kiribati (Lobel, 1980). Fish of this species, as well as a red hybrid, are being cultured on a commercial scale on Guam. The hybrid fingerlings, probably a cross or backcross of a hybrid between *Oreochromis mossambicus* and *O. niloticus*, were originally obtained from Taiwan, and although the fish breed readily in the ponds, additional importation of Taiwanese stock has occurred periodically.

The herbivorous *T. zillii*, which is cultivated in Africa, is not cultured in the region at present, but it has become established in the streams and in a man-made reservoir, Fena Lake, on Guam where it was introduced in an attempt to control the submerged vegetation (Brock, 1955, 1956; Best and Davidson, 1981; Leith et al., 1984).

Tilapia culture on Guam has been fairly successful. The major problem is, as elsewhere, that of controlling the breeding of the fish in the ponds and the resultant overcrowding. The overcrowding leads to stunting of the fish's growth so that, even though production remains high, the fish are too small to market. Preliminary trials have been conducted on Guam in the use of a piscine predator, the peacock cichlid (*Cichla ocellaris*) to control the size of the tilapia populations in the ponds (D. Crisostomo, personal communication, August 1985). This method of tilapia population control is limited to freshwater ponds since C. ocellaris can not tolerate brackish water. The peacock cichlid was introduced to the Fena reservoir on Guam for use as a sport fish. Its native habitat is in South America.

Tilapia culture will probably continue to develop on Guam to serve the local market. However, because of the problems resulting from the abilities of these species to become established in a variety of aquatic habitats, their introduction to islands where they do not already exist should be strongly discouraged (see the section below on problems resulting from introduced species).

Giant Clams

There is considerable interest in the region at present in the cultivation of Giant Clams (Tridacnidae). This interest largely stems from the recent development of technologies for spawning and larval rearing of these species (Beckvar, 1981; Gwyther and Munro, 1981; Heslinga, 1981, 1982; Heslinga and Perron, 1983; Munro and Heslinga, 1983; Heslinga and Watson, in press; Heslinga et al., 1984). Interest in tridacnid clam cultivation has developed in many areas of the Pacific, and a large international research program on the biology and culture of tridacnids is presently underway in Australia (J. Lucas, personal communication, June 1985).

Although recent breakthroughs have spurred much of the present activity, there has been a long-standing interest in the cultivation of these species for the replenishment and management of natural stocks (Yamaguchi, 1977). Other work on tridacnids in Micronesia and nearby areas includes studies of their larval biology (Jameson, 1976; Fitt et al., 1984), the status of natural stocks (Bryan and McConnell, 1975; Hester and Jones, 1980; Hirshberger, 1980; McKoy, 1980), their growth rates in natural habitats (Bonham, 1965), and reproductive biology (Braley, 1984).

Pearl Oysters

Pearl oysters have been important items of commerce in Oceania for centuries (Oliver, 1962) and pearl culture has been and continues to be a thriving industry in the Tuamotus and other islands of French Polynesia (George, 1968; Davy and Graham, 1982; Coeroli et al., 1984, F. Blanc, personal communication, June 1985). There were pearl shell operations established at Belau and, on a smaller scale, in the Marshall Islands during the Japanese era prior to World War II (Smith, 1947; Nishi, 1968). However, no pearl culture activities are on-going in Micronesia today. The success of this industry in Polynesia and the research underway there indicate that the culture of pearl oysters may be the focus of developmental efforts in other areas of the Pacific, including Micronesia and American Samoa.

Research was conducted over a period of approximately three years by scientists at CNEXO (now EFRIMER) in Tahiti to develop technologies for the mass production of pearl oyster spat. However, the methods used in other, commercially developed, oyster hatchery technologies apparently were not successful when applied to the pearl oysters, so the research has been discontinued for the time being (D. Coatanea, personal communication, June 1985). The research focus of the scientists in French Polynesia is now on the general biology and ecology of the pearl oysters (Intes, 1984; in press). Intes and Coeroli (1985) have compiled a bibliography concerning the biology of pearl oysters.

Since hatchery techniques for pearl oysters have not been developed, seed stock must be obtained from natural spatfall. One problem with this method is that spat of the desirable pearl oyster, *P. margaritifera*, is often mixed with and, at a small size, indistinguishable from, spat of a smaller, undesirable, species (F. Blanc, personal communication, June 1985). The development of this industry in Micronesia or Samoa would require training in the techniques of inducing the oysters to form pearls. The Tahitian government is sponsoring experts to train culturists in these techniques so, presumably, the technology could be transferred to other areas as well.

The potential for cultivation of pearl shells in Micronesia and Samoa should be explored in greater detail. This type of cultivation is especially suited to protected environments, such as those of atoll lagoons where the retention of detrital materials may significantly enhance productivity (see Birkeland, 1984). Attempts at the cultivation of pearl oysters should be preceded by studies of natural stocks within the region. The abundances of natural stocks of pearl oysters are currently being evaluated in Pohnpei (M. Gawel, personal communication, December, 1985).

Other Bivalves

A number of attempts have been made to introduce the temperate Pacific oyster (*Crassostrea gigas*) to various Pacific islands (Bourne, 1979) as recommended by previous workers (Glude, 1972). Most of these have ended in failure; however, commercial production was achieved in Hawaii (Goldstein, 1984). There have been also been studies made of the indigenous oysters and clams and some of these species have been suggested as possible candidates for aquaculture development (Walters and Prinston, 1975; Day, 1977; Braley, 1982, 1984; Kamura et al., 1979; Angell et al., 1984; Glude, 1984). These projects have not led to commercial or pilot scale developments, and there has been little interest in the development of bivalve culture apart from the previously mentioned work on giant clam and pearl oyster aquaculture. There is not much of a regional market for these other species, with the possible exception of Guam with its hotel markets. In addition, the areas suitable for commercial development, such as mangrove swamps, are limited in many areas, including Guam. Another problem is the that the nearshore waters are low in both dissolved nutrients and in the standing crops of phytoplankton upon which many oysters feed. Detrital feeding bivalves, however, may have potential for small-scale development.

Research-scale projects on the fast-growing Philippine green mussel Perna viridis are now underway in Western Samoa (Bell et al., 1983; Bell and Albert, 1984) and while this species shows some promise, caution should be taken with regard to its introduction (see the section below on introduced species).

Economic Seaweeds

The islands of Micronesia do not share the traditions of seaweed use that have been reported for Hawaii and other Polynesian islands (Schonfeld-Leber, 1979).

Only a few species of marine algae are used for food in the region. These edible macroalgae, primarily Caulerpa racemosa and Gracilaria sp., are collected either for family use or to be sold in the local flea markets.

There is considerable interest in the cultivation of seaweeds in the Pacific Islands. This interest has been the largely the result of the success of seaweed farming for phycocolloid production in Taiwan (Chen, 1976), the Philippines (Doty, 1973; Parker 1975, 1976, Deveau and Castle, 1979), and other areas (Raju and Thomas, 1971). The phycocolloid industry is rapidly growing and, for the most part, it is still limited by the supply of raw materials (the seaweeds) (Doty, 1982a & b). The economic situation and the growth of the phycocolloid industry have resulted in a world-wide interest in the cultivation of seaweeds, particularly those containing either agar or carageenan. The cultivation of seaweeds for phycocolloid extraction may be well suited to remote islands, since the thalli can be sun-dried and so stored for many months. This is important where boat visits are infrequent and, even though scheduled, somewhat unpredictable.

Several species of Gracilaria from this region have been examined with regard to the yield and quality of their agar extracts (Nelson et al., 1983). In general, these species have rather low quality agar extracts relative to those of cultivated strains in Taiwan. However, an exceptional species found in Garapan Lagoon at Saipan yielded extracts within the range of those commercially cultivated in Taiwan. There have been some attempts to develop post-harvest handling procedures to increase the gel strengths of the agar extracts, but these have, thus far, met with only limited success (S. Wilkins and S. Nelson, unpublished data).

Other work on Gracilaria in this region has focused on growth (Nelson and Tsutsui, 1982; Nelson et al., 1982), physiology (James, 1981, Nelson and Tsutsui, 1981; Nelson, in press), genetics (Matlock and Romeo, 1982) and on the development of suitable culture technologies (Nelson et al., 1980). In addition, research on the potential of Gracilaria cultivation is currently underway at the College of Micronesia at Pohnpei (S. James, personal communication, June 1985)

Other species of economic seaweeds have received some attention for possible cultivation in Micronesia (Doty, 1981; Russell, 1982; Tsuda, 1982). Primarily these have been in the genus _Eucheuma_, species of which have been successfully cultivated in the Philippines. These macroalgae contain carageenan, another phycocolloid in demand on a world-wide scale. This genus does not occur naturally in abundance in Micronesia, but there have been some preliminary attempts at the development of _Eucheuma_ cultivation at Pohnpei under the direction of Dr. Maxwell Doty of the University of Hawaii. A similar project was established in 1980 at Kiribati (Russel, 1982; Why, 1985). The Kirabati project has produced and exported a limited amount, about 2 tons per month, of dried seaweed. Also, there is an experimental _Eucheuma_ project underway at Kosrae for which the major problem is finding a market for the small volume of dried algae produced thus far (J. Robinson, personal communication, August 1985).

The edible green alga _Caulerpa racemosa_ is popular as a fresh vegetable and is marketed on a small scale on Guam. There has been some cultivation of this species in the Philippines for export to Japan (Doty, 1981), but at this time, there is little potential for cultivation of this alga in this region, primarily because it is difficult to preserve or store.

Another possibility for seaweed or aquatic plant cultivation in the region is for use in water treatment

(Nelson and Tsutsui, 1981; Nelson et al., 1981). The use of aquatic plants for waste water treatment has considerable potential for use in the tropics, because of the stable environmental temperatures. Aquaculture systems for water treatment have been instituted in several areas of the continental United States (Haines, 1975; Ryther et al., 1975, for example) and this concept deserves more attention for application in this region.

There has been some attention given to the cultivation of seaweed as food for other organisms (FitzGerald, 1976), but this is likely to remain only a peripheral activity. It should be mentioned however, that a large portion of the Gracilaria production in Taiwan is apparently used as feed in the culture of abalone (Y. M. Chiang, personal communication, 1984).

PROBLEMS WITH INTRODUCED SPECIES

One striking feature of an examination of species with at least a biological/technological potential for aquaculture production within the region is that quite a large number of such species exist. Virtually any tropical species, and a number of temperate species, cultured today has potential for growth and production in the tropical environments of these Pacific islands. This has led to a number of aquatic and marine species being introduced to the region specifically for evaluating their aquaculture potential. These introductions are often made somewhat indiscriminately, and if this situation continues, regrettable ecological disturbances could result (Lobel, 1980; Simberloff, 1981).

Ecological problems, such as the displacement and extinction of endemic species, which have resulted from the introduction of exotic species into aquatic ecosystems have been well documented (Lachner et al., 1970; Courtenay and Robbins, 1973; Maciolek, 1984). Such disturbances are even more likely in the relatively fragile and little known inland aquatic habitats of these islands. Species which exist on islands generally are not faced with competitive pressures as severe as are those from continental regions; thus, species which are introduced to islands may displace, or even cause the extinction of, endemic insular species.

Another problem with the introduction of exotic species is the potential for the inadvertent introduction of pests or diseases. This problem is not uniquely associated with the introduction of exotic species, but is also a problem with such practices as importing fry or fingerlings for stocking aquaculture ponds, even when the species in question occurs naturally in the area. If juveniles are to be imported in order to sustain an aquaculture industry, then some quarantine facility is necessary to reduce the potential hazards of this practice.

Aquatic introductions should be undertaken with caution and only after thorough studies of the potential impact on the native fauna have been completed. Local species should be developed for aquaculture in preference to introduced species whenever possible. Regional or local governments should establish screening committees for the purpose of evaluating proposed introductions.

RECOMMENDATIONS

Interest in the development of aquaculture in this region is expected to increase in the future as the reefs are becoming overfished as a result of population pressure, the use of modern fishing equipment, and the breakdown of traditional methods of conservation. Aquaculture is needed for supplementing the food resources of the area as well as for the replenishment of depleted stocks of fishes and invertebrates. In addition, the economic and political instability of some countries in nearby areas should entice companies involved in aquaculture to consider investing in the Pacific islands which are affiliated with the United States. The needs of the island territories and nations of this region should not be neglected.

The major constraints to aquaculture development in this region are listed in Table 2. Listed below are recommendations for actions which may remove or reduce the impact of these constraints. Some of these are of a general nature by necessity since local constraints and available options obviously vary greatly between specific sites.

Development of regional hatcheries for selected species

Any aquaculture activity requires a source of juveniles for stocking. The development of local or regional hatcheries would be one solution to the problems now faced with obtaining juveniles of potentially valuable candidates for aquaculture development. Regional hatcheries, if successful, would reduce the dependency of culturists on undependable outside sources. They would also serve to prevent the introduction of pathogenic organisms, parasites or other aquatic pests which could prove to be disastrous for the the future of aquaculture in the region.

Federal funds should be made available, possibly through the Office of Sea Grant or the United States Department of Agriculture, to fund the development of regional hatcheries. Specifically, the Micronesian Mariculture Demonstration Center at Belau and the Fadian hatchery facility on Guam should receive long term (five year) support with the goal of eventual self sufficiency of these operations.

Development of aquaculture advisory services

Many, initially enthusiastic, aquaculturists become discouraged as a result of management problems or inflated expectations. This problem could be alleviated through proper counsel from knowledgeable extension agents, extension specialists and marine advisory agents. There is a general lack of such services for most of the region.

On Guam, a Marine Advisory Service is funded through the Office of Sea Grant as part of the University of

Guam/University of Hawaii Sea Grant program. This service should be expanded, via additional earmarked funds to the Guam-Hawaii Sea Grant program, to other U.S.-affiliated Pacific islands. An Aquaculture Advisory agent is also stationed at the University of Guam. This position is funded through the University of Guam College of Agriculture and Life Sciences. A similar program could be initiated for the Federated States of Micronesia since the Community College of Micronesia at Pohnpei is a Land Grant institution. This is an action that should be considered by the administration of the Community College of Micronesia.

Extension service and Marine advisory personnel should be supported in residence at the branches of the Community College of Micronesia and their efforts should be coordinated through the programs at the University of Guam.

Subsidization of air transport

Transportation is a problem in the Pacific islands, and one which restrains aquaculture development. Even routine mail deliveries are jeopardized at times by the lack of airline services. The costs of air-freight within the region, together with the general lack of airline services, greatly hinders the development of aquaculture in this region. As a result, it is difficult and costly to obtain needed equipment, supplies and feed. The profit margins are also reduced on aquaculture products destined for export. Some form of government subsidy for the shipment of aquaculture supplies and products should be considered to help remedy this situation.

Development of sustained research and development programs

The research priorities of these islands rarely correspond to the national priorities, since many of the species which are of interest in the region would not be considered for culture in the continental United States. In addition, adequate research funds for aquaculture have been difficult to obtain on a sustained basis, and projects need several years, at best, to develop from experimental stages to commercially viable operations.

For example, the Guam Sea Grant Projects are administered through the University of Hawaii and, therefore, must compete with projects of interest to the state of Hawaii. Some of these funds have supported aquaculture research on Guam, but these funds are limited (approximately $80,000 per year at present) and must be distributed among a number of other projects, including the Marine Advisory Service. Additional funds should made available to the University of Hawaii/ University of Guam Sea Grant program specifically for the support of aquaculture research within the region.

Limited funds for aquaculture research have also been available through the HATCH program of the United States Department of Agriculture. These funds have supported projects at the University of Guam and the Community College of Micronesia at Pohnpei. Local matching funds for aquaculture have been difficult to acquire and proposed aquaculture research projects must compete with those in the various fields related to agriculture. The HATCH funds are used to fund projects over longer periods than those of Sea Grant, and often support is granted for periods of five years. This type of funding should be continued and can now be more effectively used since the requirements for local matching funds have been recently relaxed.

Additional funds should be appropriated to the United States Fish and Wildlife Service specifically to support a program, with a resident scientist, in the region. The resident scientist could assist in aquaculture research, especially in the evaluation of proposed species introductions. Evaluations of this nature must be supported with additional research on the ecology of the island stream ecosystems. The resident scientist should be stationed at the University of Guam and should have a budget which would enable the other U.S.-affiliated islands of Micronesia to be served.

Also, the National Marine Fisheries Service branch in Honolulu theoretically serves the needs of the Pacific islands. Funds to this office should be increased so that at least one fishery scientist can be permanently stationed at Guam. Presently, there is an individual from the National Marine Fsheries Service stationed on Guam, but he is concerned only with enforcement of fishery regulations. Ideally, an institutional sharing arrangement could be worked to allow a resident scientist to work at the University of Guam Marine Laboratory. This fisheries scientist could aid in the development of aquaculture and fisheries throughout the region.

Also, it should be noted that research projects do not always lead directly to commercial development. However, these are still valuable even when they identify constraints or indicate that specific aquaculture activities are not feasible. An assessment of the value of research projects should not be based solely on whether or not they lead to commercial operations. Baseline research on potential aquacultural candidate species is still needed, and funds for this purpose should not be curtailed.

Need for regional coordination

Regional coordination in the planning and development of aquaculture is highly desirable. It would be useful for the local government agencies involved with aquaculture development to convene regional technical conferences for these purposes. Many of the island groups have common interests in aquaculture development, and this enhances the value of such conferences. Also, it should be noted that these islands are not often represented at international meetings dealing with aquaculture and marine resources. One example, where regional representation could be strengthened, is the Coral Reef Symposium which is held every four years; another is the Pacific Science Congress. The contacts made and the information gathered at such international meetings would facilitate the development of aquaculture within the region. Representatives of the local island governments should be sponsored, perhaps by the Office of Technology Assessment or by the Office of Sea Grant, to attend regional technical conferences and appropriate international meetings.

Need for Marketing and Economic Analyses

There is a need for economic feasibility studies of proposed aquaculture development schemes. Obviously there is a big difference between the biological/technological feasibility of a culture operation and its economic feasibility. Marketing and economic studies relevant to Pacific island aquaculture development should be funded, perhaps through the Department of Commerce or via the Office of Sea Grant. The biological/technological feasibility of an aquaculture venture is a necessary, but not a sufficient, condition to allow its commercial development.

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Table 1. Species which have been cultured on a commercial or a subsistance basis in the U.S. Pacific Insular Areas.

Species	Location	Culture System	Comments
Freshwater prawns	Guam, Belau	Freshwater ponds	limited by the supply of post-larvae
Marine shrimp	Guam	Brackish ponds	Occasional, limited by supply of post-larvae
Milkfish	Guam	Brackish ponds	Fry obtained from Taiwan
Tilapia	Guam, Yap	Freshwater and brackish ponds	Major problem: over reproduction
Eels	Guam	Freshwater ponds	Discontinued, reason unknown
Asian catfish	Guam	Freshwater ponds	No juveniles available
Marine fishes	Pingelap	Reef enclosures	On-going, family operation
Giant clams	Belau	Cement tanks	Hatchery
Seaweeds	Pohnpei	Reef-flat	Trial basis
Turtles	Guam	Freshwater ponds	Discontinued, marketing problems

Table 2. Constraints to aquaculture and mariculture development in the U.S. Pacific Insular Areas.

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1) There are insufficient local sources for post-larvae and juveniles for stocking.

2) Shipping costs in the region are prohibitive.

3) There are insufficient technical advisory services avaiable in the region.

4) There is a lack of information in general about local species suitable for aquacultural development.

5) There is a lack of baseline information to enable rational assessment of the the potential impact of introduced species to the aquatic habitats of the region.

6) There is a need for baseline marketing and economic studies for use in aquaculture planning and development within the region.

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Background Paper No. 3

THE DEVELOPMENT OF NEARSHORE FISHERIES IN THE U.S.-AFFILIATED PACIFIC ISLANDS

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

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ACKNOWLEDGEMENTS

This paper represents only a small contribution to a much larger study of the economic potentials in U.S.-affiliated Pacific islands. The author is thankful for having been chosen to make such a contribution and would like to congratulate the Office of Technology Assessment and the Congress of the United States for undertaking this study. It is now 40 years since the United States accepted responsibility for many of these islands. Such a comprehensive effort is long overdue.

Special thanks are due to Ms. Carolyn Imamura of the Pacific Basin Development Council for her assistance with technical support and liaison. The author is grateful to Dr. Charles Birkeland of the University of Guam Marine Laboratory for several useful comments. Thanks also go to Ms. Kitty Simonds and Mr. Justin Rudka of the Western Pacific Regional Management Council for their helpful and candid review of early drafts.

In the end, however, the author concedes that many of the positions taken in this paper reflect subjective appraisal and circumstantial evidence acquired during 20 years personal involvement with fisheries of Micronesia. Hard data on many aspects of island fisheries is simply not available, and the author accepts full responsibility for the judgments presented in this paper.

ABSTRACT

During the 3,000 years prior to Western contact, islanders developed extremely efficient processes for marine resource harvest and management. These processes were based on a system of reef and lagoon ownership, a reciprocal distribution system, and a keen understanding of nature and man's part in nature.

Traditional management and conservation processes have been seriously disrupted by the introduction of modern fabrication, harvest, preservation and transport technologies. This disruption has been accelerated by the economic pressures of commercialization which accompany fast-growing urbanization. The public property, open-access philosophy embodied in U.S. marine law directly conflicts with traditional island conservation mechanisms; thus, the effectiveness of modern conservation legislation has been constrained from the outset and diminished in effectiveness.

Scientific information on the current status of inshore marine resources is fragmented and inconclusive, and generalizations about such a vast and diverse geographic area can lead to faulty conclusions. It appears, however, that inshore marine resources are under some significant stress near urbanized areas. The degree of stress lessens with distance from urban centers.

Reef productivity appears to be more than sufficient in the aggregate to meet the subsistence needs of island populations; however, such aggregate comparisons may lead to over-optimism because they fail to take into account the diversity of reef organisms and their dispersion among widely scattered islands. Subsistence harvests continue to make a major contribution to the standard of living even in the most urbanized islands. Commercial development potentials for inshore fisheries are limited to small-scale ventures. Species diversity and dispersion make economies of scale difficult to achieve. Opportunity costs of labor and wage rates in general are relatively high by world standards. Long-term net social benefits will probably be maximized by concentrating inshore fisheries development activities on the improvement of small-scale local marketing and subsistence utilization.

Offshore pelagic resources offer the best opportunity for the expansion of small-scale island fisheries--be they commercial, recreational, or subsistence. As inshore resources come under greater pressure, fishermen are increasingly moving offshore. Unfortunately, the impact of U.S. law and policy regarding "highly migratory species" has been to place effective control of offshore pelagic resources in the hands of foreign nations and multinational corporations. These institutions often show only cursory regard for small-scale subsistence, recreational and artisanal needs of Pacific islanders.

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BACKGROUND AND SETTING

To the casual observer, what is commonal and general among the U.S.-affiliated Pacific island peoples may be readily apparent, but to understand regional fisheries issues requires an appreciation of the diversity and complexity of both the area and its inhabitants. More than 2,100 islands and islets are scattered throughout a region as large as the United States mainland. The multi-ethnic character of its residents arose from numerous migrations over some 3,000 years (Howells, 1973). More than ten different languages are spoken, and there is a wide variation in custom, stature and temperament among the 272,000 residents.

The islands themselves can be divided into three general categories: large, high islands of volcanic and limestone uplift topography; low, coral atolls situated on the barrier reefs of associated lagoons; and small, raised islands with no lagoons and only fringing reefs (Baines, 1982). Atolls are found throughout the American Pacific, but are most numerous in the Marshall Islands. Large, high islands are characteristic to the Caroline and Mariana chains and American Samoa; however, the high islands of the Marianas and American Samoa have only fringing reefs, while those in Truk and Palau are associated with large lagoons. In addition to geologic variation, there are differences in the amount and seasonality of rainfall, wind and tidal conditions throughout the area. Cyclonic storms (typhoons) sometimes cause great damage in the Carolines and Marianas (Holliday, 1975), but are seldom experienced in the Marshalls.

Climatic and geologic variations have had a strong bearing on many of the differences which can be observed among island inhabitants, including the diversity of traditional fishing technologies and associated customs and laws. The high islands are blessed with abundant water and other land-based resources. Therefore, although fishing was an integral part of the traditional high island socioeconomy, it was never as absolutely essential to life as it was on atolls and small, raised reef islands which generally have a paucity of fresh water and arable land.

Although it is common for Westerners to perceive traditional technology and way of life as simple, relaxed and unsophisticated, nothing could be further from the truth. Before Western contact occurred, the islanders fought wars, traded, fished and colonized across thousands of miles of ocean, navigating by very accurate traditional methods in vessels of sophisticated construction and design (Gladwin, 1974). Fishing technology was also sophisticated in nature. The myriad of languages spoken by Micronesians in the Carolines, Marshalls and Marianas, and by Polynesians in American Samoa, Nukuoro and Kapingamarangi, all reflect an unbelievably rich vocabulary for dealing with fishing and marine activities (Brower, 1981). In fact, this vocabulary is so rich and precise that in many locations it rivals Western, scientific nomenclature; translation often presents serious problems due to a poverty of appropriate English synonyms.

At times, there were elements of sport and competition involved, but seldom in traditional economies was fishing ever practiced for its recreational value alone. Those who attained great fishing skill were held in high esteem and were accorded significant social prestige. Their recommendations regarding ocean resource management were highly regarded by the community. Fishing knowledge, handed down from generation to generation, was a form of property of great personal value to the holder and, thus, not lightly shared with others in the community (Johannes, 1981). The "market system" as we know it did not exist. Profit in a monetary sense did not motivate fishermen. Fish were distributed through complex systems of reciprocal exchange and barter between and among large extended families (Hill, 1978). Even today, the majority of fish caught by island fishermen do not enter monetary markets (Knudsen, 1985; Johannes, 1979; Milone, et al., 1985).

Harvest methods, distribution patterns and customs differed, but these patterns resulted in an apparently effective resource management system in all cases. Islanders understood and practiced the principles of property rights, resource ownership and limited entry long before such concepts came to the attention of Western scientists. Rights to harvest certain species or to fish in certain grounds were often held exclusively by particular families or other specific groups within the community (Sudo, 1984). Limited preservation techniques--primarily smoking, drying and frequent reboiling--caused fishermen to avoid over-explotation beyond what was currently needed for community food. The sea itself was the storehouse, the preserver and the provider. Islanders also knew much about the life cycle of many organisms and their patterns of seasonal abundance (Johannes, 1981). In many cases, traditional harvesting techniques required a relatively large standing stock, or biomass; therefore, stock depletion would automatically reduce harvests sufficiently to preclude long-term resource damage. Technologies were species-specific and not apt to damage other than the target resource. The efficiency of traditional resource management and distribution is supported by abundant evidence of relatively high pre-contact population densities on most Pacific islands--in many cases higher than densities which exist today (Vayda, 1968).

One central concept seems to pervade the complexity of all traditional island fishing technology and social structure: Man is a part of nature, not apart from nature. There is unity and interdependence among all creatures. Technological innovation is almost always viewed as a means for adjusting to the environment, rather than as a means of controlling or manipulating the environment. Attempts to outplan nature and change the inevitable are perceived as a foolish waste of time. Seldom are Westerners cognizant of the conceptual differences which separate them from islanders and block mutual understanding regarding nature and conservation.

Such differences in thinking are best exemplified by the great island navigators who even today demonstrate their ability to travel accurately over vast distances without the aid of compass, sextant or other modern devices (Gladwin, 1974). These navigators conceptualize their canoe as standing still while the rest of the world--stars, fish, birds, waves and islands--goes past. The navigator makes adjustments to sail, speed and direction in relation to what exists around the canoe at any point in time. He knows the significance of a change in wave pattern, which he detects by feeling the water with his hand or listening to the sounds of the canoe. He never has reason to ask why the waves change cadence as islands move by the canoe, or why the cloud patterns fortell the coming of an island far over the horizon. Western science, with its own cultural bias toward the logic of cause and effect, does not serve a practical place in the navigator's world. There is no need to know why; it is simply a need to know. Because of such conceptual approaches to life, islanders often have great difficulty embracing the Western approach to fisheries management and conservation.

From the 17th through the 19th centuries, Spain, England, Germany and Holland exerted varying degrees of influence on the U.S.-affiliated Pacific islands. For the most part, these nations were primarily concerned with land-based resources, agriculture and trade. Little commercial attention was paid to fisheries by any of these colonial powers. Fishing in a commercial sense began only in the 20th century with the arrival of the Japanese and the Americans. Some full-time commercial fishermen have evolved, but most are only part-time, and almost all contribute heavily to the non-market subsistence sector (Orbach, 1980; Johannes, 1979; Milone, et al., 1985).

The semi-commercialization of nearshore marine resources has had varying impacts on both the traditional subsistence harvest and the traditional management/conservation structure (Baines, 1982). The extent of this impact varies among islands depending upon resource abundance, population parameters and degree of exposure to monetary markets. There seems to be little opportunity for large-scale, commercial development of nearshore resources in most of the U.S.-affiliated Pacific islands. Lack of such potential should not lead the reader to discount the importance of these resources in the lives of island people. Fish provide a protein mainstay as well as a pillar of cultural heritage. Damage to these resources will have an extremely high opportunity cost in terms of food stamps, public assistance and food imports, not to mention the social costs of diminished self-esteem which accompany reduced self-sufficiency.

HISTORICAL TECHNOLOGIES

Much of what we know of indigenous island fishing technology is inferred from our understanding of methods presently used on islands with relatively little Western contact. The people and customs of these islands offer a cloudy looking-glass into the past (Baines, 1982). The "generic" fishing techniques discussed in this paper were practiced throughout the U.S.-affiliated Pacific islands; however, there are literally hundreds of variations designed to fit the special environmental and resource characteristics of each unique island.

The importance of fishing to all Pacific islanders is underscored by the importance of fish in their diet. Recent studies in Tuvalu and Kiribati (Zann, 1983) indicate that finfish are served at between 53 percent and 74 percent of all means, and fish consumption averages 400 grams (14 ounces) per person per day. Studies in the Marshall Islands (Milone, et al., 1985) and in Guam (Callaghan, 1977) show similar high fish consumption patterns. In addition to finfish, hundreds of marine organisms are eaten: algae, invertebrates, molluscs, crustaceans and echinoderms. Based on other studies (U.S. Department of Interior, 1949), it seems reasonable to conclude that in the past, just as in the present, consumption of large quantities of marine organisms was essential to life throughout the U.S.-affiliated Pacific islands. Table 1 provides some modern-day data on fish consumption and harvest patterns which are probably similar among most atoll or raised reef islands and have changed little over centuries.

The degree to which inshore and reef technologies dominate offshore technologies depends largely on the size of the lagoon and reef environment relative to the island's population size and extent of agricultural resources. Inhabitants of small, raised reef islands, such as Satawal and Fais near Yap, and Tobi and Sonsorol near Palau, are very much dependent on the bounty of the open sea and, therefore, offshore technologies dominate (Gillet, 1984). These islands have little or no lagoon and reef area. Pelagic fish such as tuna, bonito, and especially flying fish, constitute approximately 70 percent of the finfish diet in these small, raised reef islands (Zann, 1983).

In days past, the tuna and bonito were caught by trolling from sailing canoes in the open ocean with lures constructed of wood, shell, feathers and sennet (Johannes, 1981). The shape and glitter of the lures was provided by mother-of-pearl. Hooks were of wood or turtle shell. The lures were trolled using handlines of sennet. In some islands, the lures were attached by sennet and hibiscus fiber to a long pole which was used to flip the fish aboard the canoe (Gillett, 1984). Drifting logs, which tend to entice pelagic fish to aggregate, and feeding bird flocks provided signals that fish were present. F9ishermen have long known that some seasons bring more logs than others, and from the behavior of birds what types of fish to expect. Figure 2 illustrates the complexity of knowledge possessed by Tobi islanders regarding current patterns and fishing locations around their reef island.

The harvest of flying fish was and still is practiced to a greater or lesser degree throughout the U.S.-affiliated Pacific islands; however, it seems to have been perfected most by the small, raised reef island and atoll dwellers. In most cases, fishing was carried out at night using coconut frond torches. Fishermen in canoes used artificial light to confuse the fish and long-handled nets or spears to harvest them (Johannes, 1981). Flying fish were also harvested by trolling with crab leg bait during daylight hours (Brower, 1981).

Inhabitants of large atolls or high islands with large lagoons were generally blessed with a wide selection and abundance of marine resources. These people were less dependent upon open sea fishes such as tuna and flying fish. Dietary patterns on large atolls reflect a marked reduction in the importance of pelagic species and a marked increase in the consumption of lagoon and nearshore marine resources. These differences in catch and consumption of lagoon and nearshore marine resources. These differences in catch and consumption patterns are reflected in Table 1. Many of the traditional fishing methods used on atolls and raised reef islands also were used by the people of large, high islands in the Carolines and the Marianas

(Jennison-Nolan, 1979). Pelagic fishing was, of course, emphasized even less by these people since in most cases their islands have abundant terrestrial resources, rich mangrove swamps, tidal flats and extensive reef ecosystems.

Despite a diversity of resource abundance and differing climatic conditions, the traditional fishermen of all islands, without exception, combined available physical natural resources with a keen knowledge of fish behavior, food preferences, spawning patterns, predator-prey relationships, and climatic and oceanographic influences (Johannes, 1978, 1979, 1981). One of the most universally practiced techniques of fishing involved the herding of certain species into shallow areas or onto beaches. Large numbers of people formed a line some distance offshore. Often, a sennet rope with coconut fronds was stretched between them. The group would then move over several hundred yards of reef, splashing and herding the fish ahead of them. The idea was to form a semicircle around the fish, gradually reducing it in size until the fish aggregated near the shallows or a beach. This technique illustrates a precise understanding of fish behavior. Even though fish could easily swim under the rope and through the legs of the fishermen, they do not, and in fact, they cooperate in their own capture. Once aggregated, the fish are harvested by spear, dip net, or simply by hand. On some islands, similar aggregation was accomplished using a large surround net or beach seine made of sennet and hibiscus fibers with hibiscus floats and shell weights. The effective use of such nets required smooth sandy bottoms, not a frequent condition among Pacific islands.

Portable fish traps, lattice boxes with funnel or maze-type entrances, were used in almost all islands. The traps were constructed of local woods lashed together with sennet rope and weighted down with rocks. Considerable knowledge was required for proper trap placement on the reef. The fisherman must be familiar with the territorial and migratory habits of the targeted species. The trap was often camouflaged and its entrance had to be situated properly with respect to the currents. Periodically the trap was removed and the captured fish brought to shore or placed in a canoe or bamboo raft. Alternatively some traps were designed to permanently remain in place and the fisherman dived to remove the fish either by hand or by spear (Johannes, 1981).

Handline fishing was a technique practiced throughout the Pacific islands during both day and nighttime hours (Zann, 1983). The lines were made of sennet and hibiscue fiber. The hooks, or gorges, were made of wood, turtle shell or bone. The bait used depended on the known food preferences and feeding behavior of target species. Rocks were used as weights to sink the baited hook to proper depths and sometimes chum was distributed in association with the bait. Fishermen could tell from the feel of the line what type of fish was biting the hook. A knowledge of reef ecosystems and their dynamics, both day and night, was necessary to successfully target specific species. Handlining for sharks involved the dangerous task of enticing the shark to follow bait (usually hand-held) through an open noose beside the canoe. At the proper instant, the noose was closed, leaving shark and fisherman to battle on the sennet handline. Quick reactions, calloused hands and scars were undoubtedly the fisherman's trademark.

The use of fish poison was understood by most Pacific islanders (Johannes, 1981). Typically, the toxin was made from pulverized Derris root or certain species of sea cucumbers which was then spread in the water, reef crevices or potholes, often at low tide when water circulation in the area was minimal. Once anesthetized, the fish could easily be harvested by spear or hand. In most cases, unharvested organisms recovered from the stunning effects with the purging action of incoming tides.

On islands having large enough reef flats, fish weirs were commonly used (Hunter-Anderson, 1981). These are large stationary walls made of piled stone or wooden stakes placed on the reef flat to form a large funnel or "V"-shaped stockade, with the narrow end toward the sea. The large open end may cover several hundred yards of reef flat. Many species of fish venture across the nearshore flats to feed during high tide; as the tide falls, they may find their retreat to deeper water blocked by the walls of the weir. As the tide continues to fall, the fish are channeled into a holding pen or trap at the bottom of the funnel. Fishermen periodically check the holding pen and remove the entrapped fish by spear, dip net or hand.

Spearfishing was practiced both above and below water. Spears were made of woods with varying degrees of buoyance and employed a wide variety of tip designs to suit specific uses. Harpoon type spearfishing was done both while walking in tidal flats and from the prow of a fast-moving sailing canoe. Throwing accuracy demanded good eyes, instant reflexes and great muscular coordination. Adjustment had to be made for relative speed, distance, depth and light refraction. Knowledge of swimming patterns and behavior of the target species during flight was critical to success.

Underwater spearfishing was also practiced. Again, a knowledge of fish behavior was crucial. Fishermen descended quietly, often using rocks for weight, and remained motionless for several minutes while holding on to a coral outcropping. Fish with inquisitive behavior patterns were frequently the victims since they were the first to investigate this new resident in their environment. During spawning, some species became virtually oblivious to the approach of a spear fisherman. Sounds made by certain target species were well known and duplicated by the spear fisherman to entice the prey to come within spearing distance. Night spearfishing by the light of the moon or by coconut frond torchlight could be extremely productive since certain species of fish are easily speared while they sleep.

Foraging was also practiced, usually by women, throughout the tidal flats and mangrove swamps of the Pacific islands. A wide variety of invertebrates, molluscs and crustaceans were regularly harvested and eaten. Tools usually consisted of wooden pries and coconut frond baskets or creels. Seasonal patterns of abundance and behavior were well understood.

IMPACTS OF MODERN TECHNOLOGY ON FISHING

The management and conservation aspects of pre-contact fisheries were probably augmented by the inherent inefficiency of much of the gear used by traditional fishermen. Introduction of modern materials and construction has served to considerably enhance the productive efficiency and intensity of the old fishing technologies and, in many cases, served to undermine traditional management practices.

The underwater spear fisherman now has a steel shaft instead of wood and "rubber bands" of surgical rubber to propel the spear over greater distances at higher speeds than was previously possible. Glass goggles and masks greatly improve underwater vision and increase the catch per unit of effort for several traditional fishing tedhniques. Battery-operated waterproof lights allow the spear fisherman to invade the heretofore undisturbed nighttime resting places of many species.

Gas lights replace the old coconut frond torch and significantly increase the efficiency of flying fish harvest and other nighttime reef foraging activities. Fish traps are now made of galvanized chicken wire and welded steel reinforcing bars. Wire netting has now replaced the rock and wooden walls of the fish weir. Monofilament polymars, nylon and lead weights replace the hibiscus fiber and shells in nets. Steel hooks, wire and monofilament leader materials, and dacron lines have increased the working depth and catching capacity of handlines. Fish are now herded into large, fine mesh monofilament gill nets which indiscriminately capture entire schools. The outboard motor has replaced the sail and greatly increased vessel maneuverability, speed and reliability. Long-lasting resilient fiberglass has replaced the wooden hull. The pearl shell lure has been redesigned with stainless steel, lead and plastic in place of shell, wood and feathers. Most damaging of all to the environment has been the substitution of chlorine bleach products in place of traditional fish poisons. These new chemicals cannot be directed at specific target species and they destroy, rather than merely stupefy, all living organisms in the area of application.

In addition to the heightened effectiveness brought by these new materials, the introduction of entirely new methods created wholly new capabilities. Throw nets were probably first used in the Pacific islands by the Spanish in the 17th century (Jennison-Nolan, 1979). The nets are circular, sometimes up to three meters in diameter. Lead weights ring the entire circumference and the net is thrown into shallow water from a canoe or from a standing position on the reef flats. If thrown properly, the net opens to its full circumference before hitting the water where it quickly sinks to envelop any fish under its scope. The net is then drawn from the center, forcing the trapped fish into pockets around the rim. Island fishermen throughout the Pacific have become very proficient in the use of the throw net.

In addition to throw nets, a wide variety of stationary and movable surface and subsurface nets, traps and weirs has been introduced. Of these, monofilament gill nets have probably had the greatest impact. Gill nets are designed to entangle fish which attempt to swim through the mesh. Fish with a girth smaller than the mesh size pass through unharmed. Those of larger girth pass only part way through and then attempt to withdraw. The limp monofilament hooks in the fish's gill plate and the fish is entrapped. Further thrashing serves only to reinforce the entanglement. Gill nets are most frequently set in the reef passes or in the reef flats at high tide. Whether herded or not, when the tide retreats, fish attempting to move to deeper water are entrapped.

As with all other introduced innovations, it is the island fisherman's extensive knowledge of fish behavior that makes the new equipment so devastatingly efficient. The throw net fisherman approaches a school at the edge of the reef, just as the tide begins to come in and with the sun coming over his shoulder: he knows the fish cannot easily see him and are intent upon feeding while, at the same time, his ability to perceive them is greatly enhanced. The gill net fisherman knows that mullet in flight will jump when confronted by an obstacle; therefore he sets two rows of netting, one about a meter behind the other. The school of mullet is herded toward the net and, frightened, they tend to jump upon encountering the first net. But as they reenter the water at a high rate of speed, they are trapped in the second net before they can evade it.

Fishing with explosives was contribed by islanders during World War II. After the war, there remained an ample supply of unexploded ordnance, and many fishermen became self-taught ordnance disassembly experts. There have been a number of deaths and maimings, but the practice of dynamiting continues with devastating results. Along with the use of chlorine poison, it ranks as the most environmentally destructive fishing method. The coral habitat on large parts of many reefs has been laid waste by explosives and chlorine. Recovery takes many years.

Modern mechanical and electronic innovations--echo sounders, loran and hydraulics--have improved fishing efficiency immensely. Deeper and deeper resources are being tapped. Fish show up as colored blotches on the screens of electronic fish finders. Fishermen using dacron lines and lead weights can accurately place baited hooks in depths of 250 meters or more. Even the swiftest schools are no match for the speed of a fiberglass hull and outboard motor. Production inefficiency no longer acts as it did in the past to automatically control harvest. Automatic constraints are further eroded as traditional preservation techniques are supplemented with ice and cold storage.

PATTERNS AND CONSEQUENCES OF CHANGE

Contemporary fisheries in the U.S.-affiliated Pacific islands present a microcosmic cross-section of age-old fisheries problems--tragedy of the commons, overcapitalization, habitat and resource degradation. These problems are all made more complex as a market economy penetrates into the lives and cultures of traditionally subsistence peoples. A common pattern of events seems to be unfolding. The place of each island in this pattern is directly related to rates of urbanization, relative resource abundance, proximity to large markets, and availability of transportation.

Innovations mentioned in the previous chapter have brought about a reordering of community values and diminished social prestige associated with fishing. New materials have made it easier to construct durable fishing gear. As a result, traditional fabrication skills have fallen into disuse. It is now relatively easy to become a "fisherman". Consequently, the degree of respect and social status accorded fishermen has diminished. Their concerns regarding resource use receive less community attention. The modern fisherman can avoid a long apprenticeship, but then he misses its emphasis on the unity and interdependence of man and the environment. When the size of standing stocks diminishes, many traditional fishing techniques become less effective. In the meantime, the modern fisherman has become more and more dependent on imported materials to support his relatively high catch rates which the community has increasingly grown to expect and depend upon.

Published research on the productivity of Pacific coral reef fisheries is diverse, inconclusive and widely scattered. An attempt to summarize existing studies was undertaken in a monograph presented to the Fifth International Coral Reef Congress in Tahiti during the Spring of 1985 (Munro and Williams, 1985). Although this paper provides a laudable beginning, it best serves to underscore the diversity of opinion and the immensity of remaining tasks. Generalizing from available productivity data, the "... Coralline shelves with a good cover of actively growing coral reefs, sea grass beds, and algae usually produce around 3-5 mt./sq.km./yr. of neritic fishes...." (Munro and Williams, 1985). Coralline shelves are defined here as the horizontal and vertical marine environment between high water and the 200 m. contour of the outer reef. Neritic species include all shelf-dwelling organisms, of which subsistence and commercially valuable species are a subset of unknown dimension.

If a conservative yield estimate of 3 mt./sq.km./yr. is applied to total lagoon areas and the results are compared with minimum daily protein requirements, the picture is not altogether encouraging for the potential commercial development of inshore marine resources. This comparison, along with measures of population density, growth and distribution, are presented in Table II. The implications of data presented in Table II are echoed in the recently completed Central, Western, and South Pacific Regional Fisheries Development Plan which states that "... however extensive the present yield from reef and lagoon environments may be, there is probably little potential for expansion of inshore fisheries in most areas, other than that which will naturally occur as island populations grow" (Pacific Basin Development Council, 1983).

American Samoa, the Commonwealth of the Northern Marianas, and Guam are net importers of protein, as they have been for some time. Guam imports over 350 mt. of fresh and frozen whole fish each year (Myers, et al., 1983).

Palau, the Federated States, and the Marshall Islands appear to have a resource yield potential greater than current domestic protein requirements; however, several factors tend to diminish the true importance of these apparently under-utilized resources. First, the excess inshore resources are distributed in small amounts among hundreds of islands scattered over thousands of miles. Second, urban populations are growing at such rates (Spoehr, 1970) that current excess yield potentials will not last long. Third, use of explosives and chlorine, as well as siltation and pollution due to terrestrial degradation, may in some areas reduce coral, grass beds and algae to levels which will no longer provide sufficient nutrient recycling to support yields of normal magnitude (Birkeland, 1983).

A rather consistent scenario of fisheries development and depletion seems to be emerging throughout the U.S.-affiliated Pacific islands. The scenario is in various stages of realization throughout the area. Table II provides some intuitive indication of the present position of various island groups in the scenario which is expanded upon below.

Urban centers are growing as rural, or outer island, dwellers immigrate in search of better education and employment opportunities (U.S. Department of Commerce, 1982). Commercial fish markets--often cooperatives--are established to serve the emerging cash economies of these urban centers. Increased subsistence and commercial fishing, along with habitat degradation, put extreme pressure on urban center island reef resources (Hill, 1978). As marine products become scarce, the market prices are driven upward. Rising prices encourage even more intensive harvest efforts, and traditional reef tenure systems near the urban centers are gradually eroded. Traditional wealth and prestige are redistributed with little hope on the part of losers for satisfaction in court. The public property, open-access philosophy embodied in the U.S legal system conflicts directly with island conservation mechanisms and islanders' convictions that lagoon, reef and sea are no less ownable as private property than are houses, canoes and coconut groves.

As the rural-to-urban migration proceeds, rural reef resources are impacted positively because rural subsistence needs are reduced; however, as the urban market demand grows, so does the pressure upon outer island resources. In the name of economic development and more equitable income distribution, governments subsidize the preservation and transport of outer island resource shipments to the urban center: the rural island subsistence fisherman is transformed into a part-time commercial fisherman. His harvest efforts now become repsonsive to rising market prices rather than to traditional distribution systems and subsistence needs. Because of well-intentioned subsidies for vessel purchase, fuel, ice, freezing and transport, he now finds it more profitable to harvest far more of the resource than he ever would have in traditional times or in a non-subsidized environment. His modern, but often less selective, equipment aids the harvest. Those species most preferred by the urban dwellers command the highest prices and thus receive the greatest effort. Should a directed fishery be impossible or uneconomical, less commercially valuable reources may be unintentionally over-harvested in the process of capturing the target species.

As urbanization continues, the reef resources are over-harvested in an ever-widening area emanating from the urban center (Munro and Williams, 1985). The radius of depletion depends largely upon the relative prices of fish in the district center markets and upon costs of harvest and transport from rural areas. As long as there is a profitable gap between market prices and costs (and fish are available), fish will continue to flow into urban centers from rural villages. Much of the economic rent is captured by urban businessmen and consumers rather than village fishermen and subsistence harvesters. To the extent that economies of scale are possible, fishermen will tend to invest in larger boats, larger nets and ever more sophisticated technology. Governments, with the best of intentions, aid in this over-capitalization by subsidizing with low-interest loans, new vessels and gear. When costs rise, both fishermen and urban consumers have a vested interest in lobbying for increased subsidies. And so the problem intensifies.

As resources are depleted in the rural islands, traditional subsistence fishing becomes less and less productive. The old resource management and distribution systems are circumvented. Protein needs must be supplemented by canned fish imports (Wass, 1980). Islanders must increasingly make use of seasonably available offshore pelagic resources, which requires unfamiliar and costly imported technology, outboard motors and fiberglass boats. The resulting upheaval of traditional roles and community value systems in rural islands is reflected in growing structural employment and loss of self-sufficiency which stimulates further movement to urban centers--food stamps, welfare and canned imports.

As urban center fish prices continue to rise, less expensive foreign imports begin to flow into island fish markets. These imports exert a stabilizing pressure on local fish prices. Urban consumers benefit, but local fishermen are trapped between a fixed price for their product and ever-increasing costs of harvest, storage and transport. The only solution from the fisherman's viewpoint is to catch more fish more efficiently. Government-subsidized attempts to create further economies of scale simply serve to expand the circle of resource depletion and shift more of the rent into the hands of urban dwellers and out of the mouths of subsistence families. Fishermen search for high-priced foreign markets in the hope of improving their cost-revenue margin. In most cases, they are unsuccessful because of low volume and inconsistent quality, but even success brings with it a further loss of resource rent to foreign markets.

When the risk/reward relationship becomes unacceptable in terms of alternatives, full-time fishermen are attracted into other occupations. Part-time commercial fishermen with lower opportunity costs and second incomes take over the commercial fishing sector. These fishermen can afford to have lower returns while deriving some psychic value and subsistence benefits from their efforts. Ultimately, as the urban economy becomes more affluent, the part-time commercial fisherman is joined by the recreational fisherman who harvests common property resources--not for subsistence, not for monetary profit, but for the pure psychic value of the fishing experience. Because of time constraints and their willingness to accept lower catch per unit of effort, these part-time and sports fishermen are more likely to fish in already stressed grounds near urban centers.

The above scenario is in various stages of realization throughout the U.S.-affiliated Pacific islands. Guam (Amesbury and Callaghan, 1981), American Samoa (Wendler, 1980) and the Northern Marianas (Orbach, 1980) find themselves in the later stages of the scenario. Palau, the Federated States and the Marshall Islands seem to be in the earlier stages. Because of inshore depletion, more and more effort is being directed toward offshore pelagic fish.

Some western style conservation legislation has been passed in these islands in an attempt to conserve and manage the remaining inshore resources. In most cases, regulations involve net mesh-size restrictions, seasonal harvesting periods (primarily for trochus), and minimum size restrictions for some crustaceans and turtles. Water quality and environmental regulations exist in many islands. The use of explosives and chlorine is prohibited by law in most locations. However, both social and economic pressures work against successful enforcement of what few laws are in existence (Birkeland and Grosenbaugh, 1984).

CONSTRAINTS, OPPORTUNITIES AND POTENTIALS

Writers have noted the major constraints of economic development facing small Pacific islands (Fairbairn, 1971). Chief among these difficulties are isolation from large metropolitan markets; small and highly dispersed land masses with little mineral or industrial raw materials; and small but fast-growing populations with expectations rising faster than means of fulfillment. Other writers have shown how these constraints are reflected in the difficulties associated with developing inshore commercial fisheries (Kearney, 1979; Orbach, 1980). Immense diversity and seasonality of reef ecosystems requires great versatility of capital and labor. Seldom in Pacific islands can a fishery be developed for a single species alone. This need for versatility, coupled with remoteness and small size, results in high production, preservation and distribution costs which are not easily reduced through economies of scale. Further difficulties are added by the fact that wage rates in the U.S.-affiliated Pacific islands are high relative to regional standards. Therefore, most islanders have high opportunity costs in terms of alternate employment and time required to fulfill social and cultural obligations.

The Japanese have been lauded for having achieved in many islands during the Mandate period a sound degree of economic progress based upon indigenous island resources (Nishi, 1968). The Japanese administration used government subsidy and significant amounts of expatriot labor to encourage the production for export of trochus (top shell), pearl oysters, sea cucumber (Trepang), sponges, precious and semiprecious corals, turtle shell, assorted reef fish and pelagic tuna products. Close examination of available records reveals that over 90 percent of the exports by weight and value were composed of pelagic species, primarily tuna (U.S. Department of Interior, 1949). After more than two and one-half decades of Japanese fisheries development in Micronesia, exports from inshore fisheries were relatively small. In fact, inshore production was only sufficient for subsistence needs and supply of local markets for Japanese immigrants. Any significant fishery resource potential rests with offshore pelagic resources, not nearshore resources.

Most observers agree that the Japanese emphasis on commercial development of offshore pelagic fisheries was well-founded. Proper management of these resources can provide opportunities for economies of scale while at the same time allowing small-scale subsistence, commercial and recreational participation (Kearney, 1979). One of the most promising technologies for augmenting small-scale pelagic harvests is the fishing aggregation device (FAD), an anchored buoy placed adjacent to an island. Its effectiveness is based upon the long-known fact that pelagic fish congregate around any floating debris in the open ocean. Substantial concrete anchors, along with chain and polypropylene line, are used to moor the buoy in depths exceeding 200 meters (Boy and Smith, 1983). There are many theories for the aggrgating powers of floating objects. One most commonly accepted theory is that floating objects present a reference point in the void of liquid space around which pelatgic species congregate (Matsumoto, et al., 1981; Shomura and Matsumoto, 1982). Sometimes netting or short ropes are attached to the buoy and anchor line to provide a habitat for small marine organisms, which in turn provide food for the larger pelagic predators. The cost of fabrication and installation is high ($4,000-$8,000 per FAD). Life expectancy at present is 24 months or less, but placed in the right location, the FAD is extremely effective in increasing the "catchability" of pelagic fish. All FAD locations in the U.S.-affiliated Pacific islands are within the three-mile territorial boundaries. Because of the high cost, short life span and common property nature of FADs, most of them to date have been installed through government subsidy. Significant research efforts should be undertaken to increase longevity, to lower fabrication costs, and to standardize and mass produce FADs (South Pacific Commission, 1983).

There have been past efforts, and continuing studies are under way, aimed at enhancing the productivity of reef flats through the introduction of artificial habitats (U.S. Department of Commerce, 1985). Over the years, old automobiles, ship salvage and other scrap structures have been placed on reefs in an attempt to increase fish abundance. Generally these efforts have not provided long-run benefits primarily because of the short life expectancy of materials used. In most islands, outer reef slopes are very steep and have few substantial ledges. Violent wave action, currents and silting have tended to remove or cover artificial habitats. There is no question that improved reef habitat can increase fish abundance and potential harvests (Artificial Reef Development Center, 1985). Research should be encouraged on reef enhancement devices which embody longer life expectancy and greater long-run net benefits.

Continued pursuit of some development ideas initiated by the Japanese Mandate administration (U.S. Department of Interior, 1949) are still warranted. Breakthroughs in the spawning and culture of trochus (Trochus niloticus) and giant clam (family Tridacnadae) offer the possibility of reef reseeding (Heslinga and Perron, 1984; Heslinga, 1985). At present, trochus are harvested seasonally in some islands. The meat is eaten and the shells are exported for use in button and other shell products (Carleton, 1984). Giant clams, sometimes reaching weights of 100 kilograms, have in some islands been overharvested to the point of extinction. Both the meat and the large shells represent a potential export if reseeding and grow-out techniques can be perfected.

Sea cucumbers (beche-de-mer) offer some export potential today, just as they did under the Japanese administration (Uchida, 1983). Several more recent attempts to develop export markets have failed. Asian markets require a consistent, high quality product of a particular species, dryness, size, shape and color. As yet, it has not been possible to produce the required volume and consistency of quality. Natural abundance may have to be supplemented with mariculture to provide long-term economic viability. Continued efforts and research appear to be warranted.

All the U.S.-affiliated Pacific islands with the exception of Midway lie too far south to have harvestable quantities of the highly valuable pink and gold corals (Western Pacific Regional Fishery Management Council, 1979). Semiprecious black and red corals do exist in limited quantities. Extreme vulnerability to overexploitation requires harvest on a small-scale selective basis. Shells and corals in general offer some economic potential for small-scale local tourist-oriented sales. Sufficient resources for long-term, sustainable exports do not seem to be available (Uchida, 1983).

Pearl oyster cultivation and edible seaweed mariculture offer some export potential. The Japanese administration pursued both of these endeavors in Micronesia (U.S. Department of Interior, 1949). Japanese technology and marketing participation would undoubtedly be required for success in export markets today. Such joint venture approaches seem to warrant investigation. The mariculture of seaweed (Eucheuma) for industrial sales export has often been discussed (Doty, 1977); however, Asian nations seem to have an insurmountable advantage over small Pacific islands in terms of scale economies and labor costs. This advantage makes highly unlikely the long-term viability of industrial seaweed mariculture in U.S.-affiliated Pacific islands (McHugh and Lanier, 1983).

Two species of deepwater shrimp (Heterocarpus ensifer and Heterocarpus larvigatus) are fairly abundant in depths of 200-700 meters throughout the U.S.-affiliated Pacific islands (Wilder, 1977). Rough terrain and the ecological concerns of habitat destruction make trawling unacceptable. To date, trapping has shown some success but, as yet, has not proven economically viable. Trap losses are high; productivity per trap night is low. Although the shrimp have an excellent taste, large-scale harvest and marketing problems have not yet been solved (Oishi, 1983). Further investigation of this resource is warranted, however, the highly competitive and volatile nature of international shrimp markets will probably always preclude small-scale island-based participation (Robin, Rackowe, et al., 1983).

The export of crustaceans such as lobster, mangrove crab and coconut crab offer very limited potential. Pacific islands lobsters (genus panulirus) do not seem to have a density on most island reefs sufficient to warrant other than small-scale harvest for local markets and subsistence use (Western Pacific Regional Fishery Management Council, 1980). Mangrove crab (Ranina ranina) present many of the same problems. Although the product is of exceptional quality, the available habitat of mangrove swamps is simply insufficient to support other than meager, intra-regional shipments. Despite their high market acceptance, the mangrove crab and the land dwelling coconut crab (Birgus latro) appear to have vulnerability to overexploitation and habitat degradation. Further intensive research on these species is certainly justified. Breakthroughs in the culture of mangrove and coconut crabs could be of significant economic importance.

Most Pacific islands have several marketable species of bottomfish living on the outer reef slopes and offshore banks at depths of 20-300 meters (South Pacific Commission, 1983). The deeper dwelling species have become more vulnerable to harvest with the advent of echo sounders and hydraulic line pullers. There appears to be some potential for small-scale regional export of these bottomfish to high-priced markets (Howell, 1983); however, overfishing can easily take place because of somewhat limited habitat coupled with apparently slow recruitment and growth (Western Pacific Fisheries Council, 1985). Improvements in the preservation, transport and marketing of bottomfish products would certainly prove beneficial to many small-scale island fishermen.

Several of the U.S.-affiliated Pacific islands have relatively large bait fish stocks (Wilson, 1971; Muller, 1977; Lewis, et al., 1983). Commercial pole-and-line fishing vessels capture and carry such live bait to sea, where it is used to attract schools of tuna and other pelagic species. The emergence of purse seine fishing as the dominant technology for pelagic tuna harvest has reduced the international importance of pole-and-line fishing;

however, it is still done, and live bait is essential to this harvest method. To the extent that the bait resource can be utilized by locally-based island pole-and-line tuna vessels or sold to foreign pole-and-line vessels, it represents a resource of some potential value.

RECOMMENDED FUTURE DIRECTIONS

Based upon what has happened in the past, it appears that future development of inshore fishers in the American-affiliated Pacific islands should be guided by five underlying concepts:

(1) Growth must embody the idea of smallness and technical appropriateness. Economies of scale are not in most cases the answer to the success of island-based inshore fisheries (Bollard, 1978). Shoreside ice and freezing plants, as well as transport vessels, should be technologically uncomplicated, reliable and culturally compatible with island communities (Baines, 1982; World Bank, 1980). Solar and wind technology offer some possibilities for outlying islands.

(2) Import substitution and long-run self-sufficiency should be the foremost development goals. Export of inshore marine products should be fostered only when it does not negatively impact upon present or anticipated future subsistence activities and only when such exports result in a significant local retention of resource rents (World Bank, 1980).

(3) Management and conservation concerns are critical. The fragile inshore ecosystem si still an integral part of the social and economic fabric of island life. There is no hard evidence as to the present status, but circumstantial evidence leads to the strong suspicion of an ever-growing sphere of resource stress surrounding population centers (Pacific Basin Development Council, 1983; Birkeland and Grosenbaugh, 1984). Inshore resources are the social security reserve and the unemployment insurance fund of island people. The preservation and enhancement of these inshore resources can do nothing but improve the quality of life for all residents.

(4) Fisheries development and management should be carried out in as much harmony as possible with traditional social institutions. Cooperative organizations present a potential mechanism for accomplishing this harmony; however, considerable expertise--cultural, biologic and economic--is required to adopt the western cooperative form of enterprise to the island social setting.

(5) Care should be taken not to oversubsidize the commercialization of

nearshore resources. These resources are fragile and finite. An overcapitalized inshore fishery will encourage depletion--adding to the income of market participants while reducing the lifestyle of subsistence participants. Such income redistribution may not lead to desirable long-run results (World Bank, 1980 and 1981).

In the past, nearshore fisheries development and mangement in the U.S.-affiliated Pacific islands has emphasized commercial production and marketing. Resource assessments have pinpointed "under utilized resources." Government agencies have then encouraged commercial harvest of those resources. Development has been viewed as being synonymous with the commercialization of the subsistence fisherman. Little attention has been paid to either the long- or short-run opportunity costs of this "development". Management and conservation regulations have usually pursued a species specific, gear specific or seasonal format. Enforcement costs have been high and results negligible. It has now become obvious that there are relatively few if any nearshore resources remaining "under utilized". The time has come for a more wholistic approach which considers the long-run benefit of people as part of their environment. Management requires a new focus of attention on distribution of benefits as well as production. Non-market traditional production and distribution must become part of a management scheme which, when appropriate, incorporates traditional resource property rights.

Sea tenure and exclusive reef ownership form the foundation of traditional island fisheries management (Baines, 1982; Johannes, 1978 and 1981). Artificial reef enhancement, FAD placement and general fisheries management in many U.S.-affiliated Pacific islands could be greatly aided by legislation which would facilitate the incorporation of traditional reef and ocean tenure systems into management regulations. Unfortunately, island legislatures--for the sake of expediency and because of lack of alternatives--have tended to simply copy existing conservation statutes from mainland states. Legislative counsels have provided little help, either because they find it difficult to depart from the common property tradition of U.S. maritime law or because they are overburdened and generally unfamiliar with fisheries problems.

Incorporation of traditional customs and institutions into a western legal framework shouild be aided by federal initiative. Such an initiative could facilitate appropriate legislation by funding an interagency, interdisciplinary task force to assist islanders in drafting model area-specific laws. The Peace Corps, ACTION, Sea Grant and the National Marine

Fisheries Service, as well as Pacific-based institutions of higher learning would seem to be logical participants in such an effort. Task force components should involve the disciplines of fisheries biology, economics, law, anthropology and sociology. Significant weight should be accorded to the latter two disciplines. Membership should be independent of vested federal agency interests which might influence recommendations. Ideally, the project would take place over several years with little staff turnover. In this way, experience learned at one site could be used to speed work at subsequent sites. Liberal use should be made of indigenous island experts. In the end, a proper legal framework would greatly enhance local benefits from nearshore fisheries development. Families, clans and communities would be much more willing to invest private funds in the protection and acquisition of marine resources if they could count on enforcement of regulations which are in keeping with traditional standards and "the island way of life."

Until recently, it had always been assumed by island governments that excessive pressure on enarshore resources could be relieved by shifting effort to offshore pelagic resources. Japanese Mandate administrators as well as subsequent investigators (Kearney, 1979; Uchida, 1983; and many others) have realized that the only large-scale commercially viable fishery resources in the Pacific islands are the pelagic species--tuna, billfish, and associated species. Unfortunately, U.S. law and policy regarding "highly migratory species" has served to place effective control of tuna and other pelagic resources in the hands of foreign nations and multinational corporations. In fact, the current state of affairs with respect to pelagic harvests provides some reason for concern as to whether residents of the U.S.-affiliated Pacific islands will ever be able to increase small-scale commercial, subsistence and recreational harvests.

More than 100 large purse seine vessels from over a dozen countries are presently harvesting in the waters of the western tropical Pacific (Petit, 1984). These seiners are not required to report their effort or catch to any U.S. government agency. Observers are not allowed on the vessels in the western Pacific. Purse seine technology is most effective when the net is set around drifting logs or other floating objects. Such sets indiscriminately capture many different species, but only the tuna and sometimes the larger billfish are retained. Unknown quantities (certainly in the thousands of tons per year) of non-tuna species of high value to islanders are discarded dead at sea. There is serious concern in the scientific community regarding the lack of verifiable scientific data on the pelagic fishery (Shomura, 1983; Western

Pacific Fisheries Counci, 1985). At the present time, there is no evidence as to how tuna seining activity might impact on small-scale island fisheries, and there appears to be little hope of acquiring such information in the near future. This potential loss of food fish, combined with data and management voids, may eveneutlaly result in serious abuse of the long-run self-sufficiency of island peoples. With the exception of American Samoa where canneries are located, and to a lesser extent Guam where refueling and transshipment takes place, most islands benefit little from large-scale tuna fishing.

Appendix A provides a list of agencies and organizations which impact upon fisheries in the U.S.-affiliated Pacific. Upon viewing this list, it becomes immediately obvious that support for fisheries development and management is extremely fragmented. Often an agency's participation is simply dependent upon some administrator's interpretation of agency regulations. The quasi-foreign, quasi-domestic nature of some island governments makes such interpretations all the more difficult. The result is a patchwork of programs which frustrates planning at the local level and defies any simple presentation in this paper. Past critiques of federal program disorganization have led nowhere (Harville, 1980). A complete enumeration and discussion of existing and potential programs would require an additional study of some length. Certainly such an effort is needed. Perhaps it would result in some reduction in the complexity of island life, probably not.

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APPENDIX A

EXECUTIVE AGENCIES AND INDEPENDENT GOVERNMENT ESTABLISHMENTS WITH EXISTING OR POTENTIAL FISHERY DEVELOPMENT, MANAGEMENT, OR CONSERVATION IMPACTS ON THE U.S.-AFFILIATED PACIFIC ISLANDS

ACTION/VISTA

Skilled volunteer manpower

DEPARTMENT OF AGRICULTURE

Food and Consumer Services

1. Purchases of local marine products for school lunch and other food distribution programs

Cooperative Extension Service

1. Extension services and rural development (aquaculture)

Cooperative State Research Service

1. Land Grant College research (aquaculture)

DEPARTMENT OF COMMERCE

Domestic and International Business Administration

1. International commercial information
2. Export trade promotion

Economic Development Administration

1. Technical assistance and development grants to economically depressed areas

National Oceanic and Atmospheric Administration

1. National Ocean Service:
   - Nautical charting
   - Research vessels and related support
2. Commercial fisheries natural disaster assistance
3. Fishery Cooperative Services
4. Sea Grant Support:
   - Research
   - Education
   - Training
   - Advisory services
5. Coastal Zone Management Program:
   - Funding for coastal planning
   - Ensures state-federal consistency
   - Estuarine sanctuary assistance
6. National Marine Fisheries Service:
   - South West Fisheries Center
     - Basic research
     - Resource investigation
     - Data collection and analysis
     - Habitat and conservation research
     - Management and development research
   - South West Region

            Marine mammal protection
            Endangered species
            Fisheries development (commercial)
            P.L. 88-309
            S-K Grants
            Vessel loans
            Infrastructure loans
        - Fisheries management
        - Enforcement
        - Education
        - Food product inspection
    7. National Environmental Satellite, Data, and Information Service:
        - Oceanographic data
        - Weather service
        - Tsunami warning
    8. Travel and Tourism Administration:
        - Marine tourist attraction development

DEPARTMENT OF DEFENSE

U.S. Army Corps of Engineers
    1. River, harbor and waterway:
        - Design
        - Development
        - Construction
        - Maintenance
        - Associated environmental, economic and cultural research
    2. Preservation of navigable waters and wetlands
    3. Disaster recovery assistance

U.S. Navy
    1. Construction Battalion:
        - Community action services
    2. Oceanography:
        - Fleet weather service
        - Typhoon warning

ENVIRONMENTAL PROTECTION AGENCY

Water quality
Pesticide control
Toxic, liquid and solid waste control

DEPARTMENT OF THE INTERIOR

Fish and Wildlife Service
    1. Farm fish pond management
    2. Fishery research (fresh water)
    3. Pesticides monitoring
    4. Wildlife technical assistance
    5. Marine environmental quality and biological resource programs
    6. Habitat enhancement
    7. Refuge management

National Park Service

1. Park and recreation technical assistance

Office of Territorial and International Affairs
    1. Economic, Social, and Political Development

NATIONAL SCIENCE FOUNDATION

Research funding

PEACE CORPS

Trained volunteer manpower

SMALL BUSINESS ADMINISTRATION

Management assistance and loans

DEPARTMENT OF STATE

Office of Pacific Island Affairs

Office of Oceans and International Environmental and Scientific Affairs
    1. International fishery affairs
    2. Fishery treaty negotiations and GIFAs

DEPARTMENT OF TRANSPORTATION

U.S. Coast Guard
    1. Search and rescue
    2. Navigational aids
    3. Pollution control and port safety
    4. Training and licenses
    5. Maritime law enforcement
    6. Fisheries management law enforcement
    7. Commercial vessel safety
    8. Boating safety
    9. Vessel registration and documentation

OTHER BOARDS, COMMITTEES, COMMISSIONS, COUNCILS, QUASI-OFFICIAL AGENCIES, AND MULTILATERAL ORGANIZATIONS

Agency for International Development (AID)

Endangered Species Committee

Forum Fisheries Agency (FFA)

Marine Mammal Commission

Northern Marianas Islands Commission on Federal Laws

Pacific Basin Development Council (PBDC)

Pacific Fisheries Development Foundation (PFDF)

Smithsonian Institution - Tropical Research Division

South Pacific Commission (SPC)

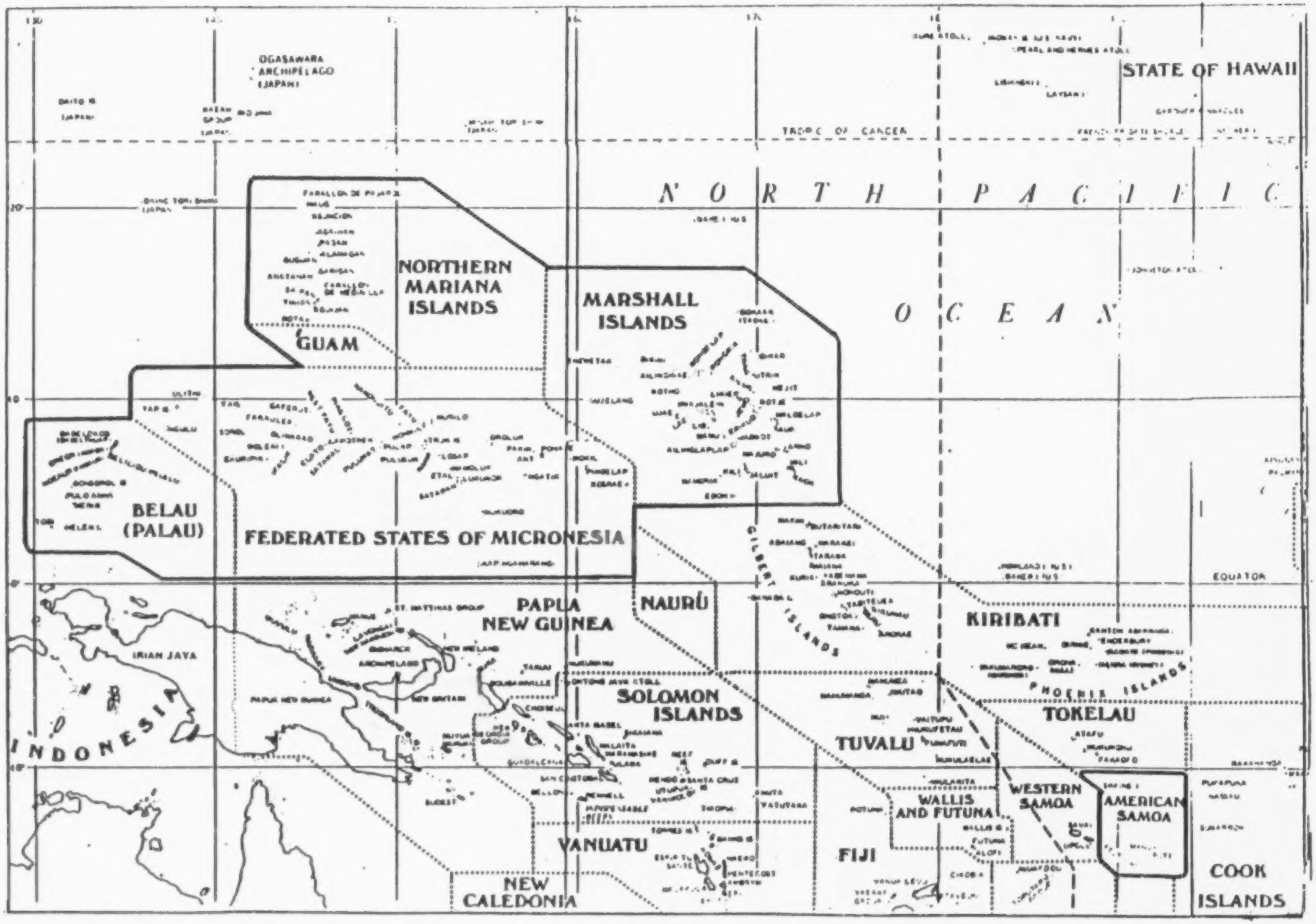
South Pacific Regional Environmental Program (SPREP)

United Nations:
- Trusteeship Council
- Economic and Social Commission for Asia and the Pacific (ESCAP)
- United Nations Development Program (UNDP)
- Food and Agriculture Organization (FAO)
- FAO/INFOFISH

Western Pacific Regional Fishery Management Council

FIGURE I

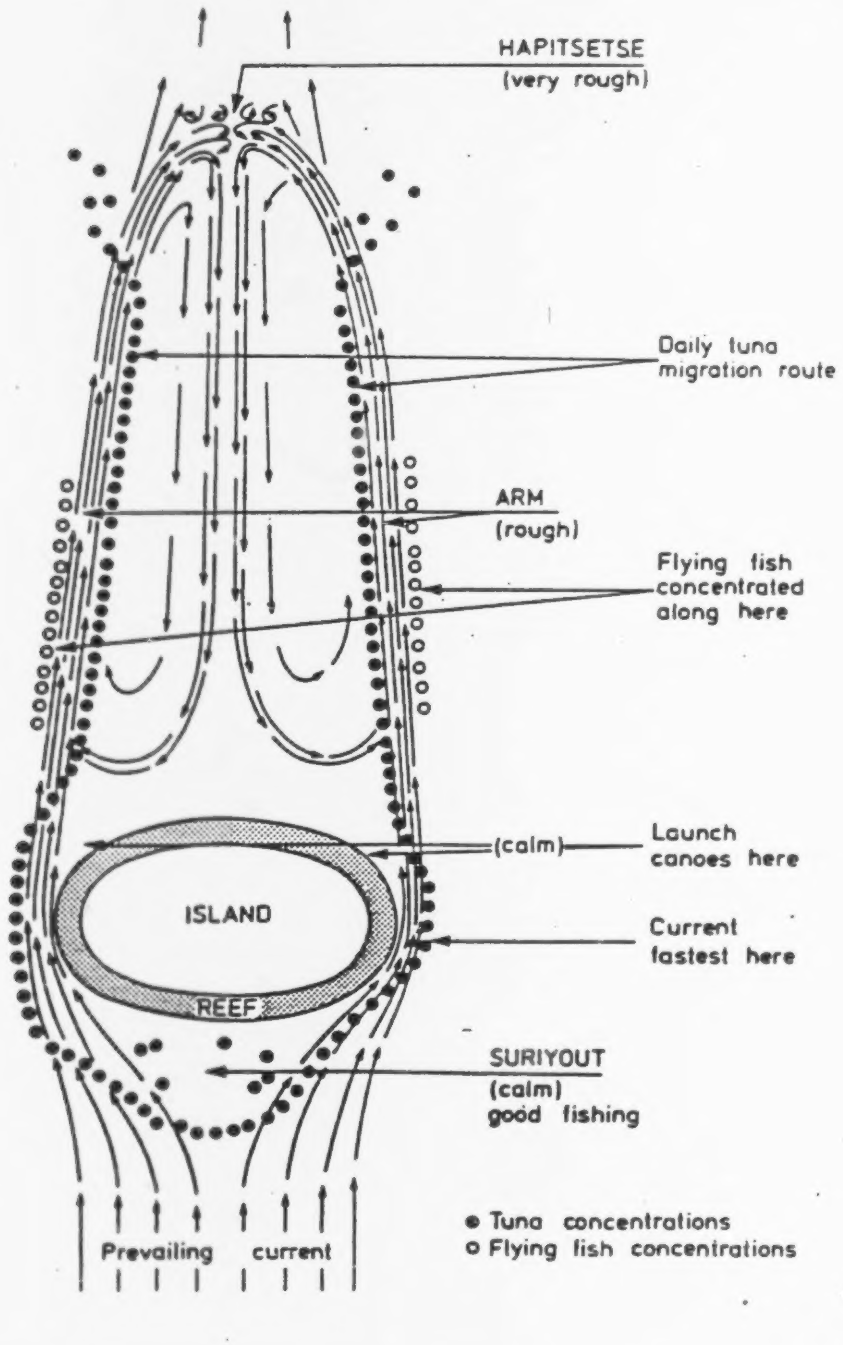
U.S.-AFFILIATED ISLANDS AND NEIGHBORING STATES


NORTH PACIFIC OCEAN
STATE OF HAWAII
OGASAWARA ARCHIPELAGO (JAPAN)
TROPIC OF CANCER
EQUATOR
NORTHERN MARIANA ISLANDS
GUAM
MARSHALL ISLANDS
BELAU (PALAU)
FEDERATED STATES OF MICRONESIA
PAPUA NEW GUINEA
NAURU
GILBERT ISLANDS
KIRIBATI
PHOENIX ISLANDS
TOKELAU
SOLOMON ISLANDS
TUVALU
WALLIS AND FUTUNA
WESTERN SAMOA
AMERICAN SAMOA
COOK ISLANDS
FIJI
VANUATU
NEW CALEDONIA
INDONESIA
IRIAN JAYA

SOURCE: State of Hawaii Department of Planning and Economic Development.

FIGURE II

Current Patterns Around Tobi Island
as Understood by Fishermen


HAPITSETSE
(very rough)
Daily tuna migration route
ARM
(rough)
Flying fish concentrated along here
(calm)
Launch canoes here
ISLAND
Current fastest here
REEF
SURIYOUT
(calm)
good fishing
Prevailing current
● Tuna concentrations
○ Flying fish concentrations

SOURCE: Johannes, R.E., Words of the Lagoon, University of California Press, 1981.

TABLE I

A COMPARISON OF SUBSISTENCE FISHING IN HOUSEHOLDS DURING JANUARY 1980

ISLAND	ONOTOA(KIRIBATI)	NIUTAO(TUVAUL)
Description	Atoll/Lagoon	Raised Reef
No. of Fish Species Eaten	45-50	12
Species Eaten (% by Weight)	Rockcod(Serrunidae) Reef Perch(Lutjanus) & Emperor(Lethrihus) ————50% Flying Fish——10% Trevally(Carangidae) —— 5% Silversides(Gerres) —— 5% Mullet(Mugulida) & Goatfish(Mullidae) ——10% Other Reef Fish—20%	Tuna————55% Flying Fish——20% Wahoo(Acanthocybius) ————15% Other Reef Fish—10%
Fishing Techniques (By Order of Use)	Gill Net in Shallow Water Handlining(Canoe) Skin Diving with Spear Spear Fishing Scoopnetting(Canoe) Reef Gleaning	Trolling(Canoe) Handline deepwater (Canoe) Scoopnetting(Canoe) Handlining Shallow Water Skin Diving with Spear
Fishing Unit	1-2 Fishermen Small Canoe	3-4 Fishermen Large Canoe
Average Days Fishing Per Week	4.0	4.9
Fishing Effort (Man Hr./Week)	27.7 hrs.	33.0 hrs.
Total Catch/Week	32.0 kg.	33.0 kg.
Catch/Effort	1.15 kg./hr.	1.00 kg./hr.
Catch Distribution	Household and Extended Family	30% to Canoe Crew 45% to Primary Fishing Household 25% to Extended Family and Community.

SOURCE: Zann, Leon P., "Man and Atolls. Traditional Patterns of Utilization and Conservation in Kiribati and Tuvalu," in Artisanal Fisheries of the South Pacific, Institute of Marine Resources, University of the South Pacific: 1982

TABLE II

POPULATION AND INSHORE RESOURCE PERAMETERS
FOR THE U.S. - AFFILIATED PACIFIC ISLANDS

ISLAND GROUPS	POPULATION (000)	AVERAGE ANNUAL POP.GROWTH (%)	PERCENT URBAN POPULATION (%)	AVERAGE AN.URBAN GROWTH (%)	LAND AREA (SQ.KM.)	POPULATION DENSITY (POP. / SQ. KM.)	NUMBER OF MAJOR ISLANDS	LAGOON AREA (SQ.KM.)	DOMINENT TOPAGRAPHY	EST. REEF PRODUCTION (MT./YR.)	EST. PROTINE NEEDS (MT./YR.)
AMERICAN SAMOA	32.3	1.9	17.5	(NA)	199	162.3	5	24	High Is., Fringing Reef, Bays	72	3,537
COM. OF MARIANAS	16.8	6.5	16.0	(NA)	471	35.4	13	35	High Is., Fringing Reef, Bays	105	1,837
GUAM	106.0	2.5	39.5	9.3	541	195.9	1	28	High Is., Fringing Reef, Bays	84	11,603
TRUST TERRI.	116.1	4.3	30.3	5.2	1380	84.2	156	22,447		67,341	12,718
PALAU	12.1	.8	51.4	4.2	497	24.4	7	1,360	High Is., Lagoons, Atolls	4,080	1,327
MARSHALLS	30.9	3.5	47.8	2.1	181	170.6	33	11,676	Atolls	35,028	3,381
FED. STATES	73.2	(NA)	(NA)	(NA)	702	104.2	58	7,411		22,233	8,011
KOSRAE	5.5	6.8	-	-	109	50.4	1	-	High Is., Fringing Reef, Bays	-	601
PONAPE	22.1	4.5	25.1	11.0	347	63.6	9	859	High Is., Lagoons, Atolls	2,577	2,418
TRUK	37.5	(NA)	23.0	12.0	127	295.2	30	5,502	High Is., Lagoons, Atolls	16,506	4,105
YAP	8.1	.6	-	-	119	68.1	18	1,052	High Is., Lagoons, Atolls	3,150	887

SOURCES: Bureau of the Census, U.S. Department of Commerce, 1980 Census of Population, Parts: 1-B54, 1-B57A, 1-A57B, and 1-A56. United States Commercial Company, U.S. Navy Military Government Pacific Ocean Areas, Maps of the Islands of Micronesia, 1946.
Estimates of reef productivity are derived by multiplying lagoon area by 3 mt./sq.km./yr.
Estimates of population protine needs are based on 300g./person/day.

Background Paper No. 4

NON-FOOD MARINE RESOURCES DEVELOPMENT AND MANAGEMENT IN THE PACIFIC U.S.-AFFILIATED ISLANDS

by

Barry D. Smith
University of Guam Marine Laboratory

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

ABSTRACT

The marine environment has supplied most of the food and material needs of the inhabitants of the Pacific islands for more than 3,000 years. Traditionally, non-food marine resources provided raw materials for manufacture of fishing implements, weapons, ornaments, currency, and dwellings. Cultural taboos limited harvests of these resources, thereby providing for sustained yields.

Non-food marine resources became the currency of commerce following contact of the islanders with European explorers and merchants. Western political, legal, and religious institutions replaced traditional practices and led to overexploitation of the these resources.

Under U. S. administration, non-food marine resources have not achieved the level of importance in island economies that was developed during the Japanese mandate. Since World War II, records of harvests have been poorly kept, and research on distribution and abundance of resources has been limited. Federal agencies with oversight responsibilities do not maintain personnel in the region to assist in development and management programs.

Technologies for development of non-food marine resources of U. S.-affiliated islands already exist. Transfer of these technologies would assist in creating employment opportunities in the islands and in stabilizing island economies. Island governments need assistance in research, extension, and education programs to develop management strategies to use resources wisely.

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1. Commercial harvests of trochus shell in Palau and Yap, 1915 to 1957. After McGowan (1958)

INTRODUCTION

Since the arrival of the first inhabitants of the Pacific islands some 3,000 years ago, the marine environment has supplied most of the food and material needs of the islanders. From raw materials in subsistence cultures to source of revenue in modern international commerce, non-food marine resources have been an integral part of island economies.

For the purposes of this paper, non-food marine resources mean biotic and abiotic resources occurring between the mean high tide line and extending to and including coral-reef resources to an approximate depth of 600 feet. Thus, products of molluscs, cnidarians, macroalgae, mangroves, sharks, and turtles, as well as mineral deposits are encompassed in this definition. The commodities produced from these resources include jewelry, ornaments, pharmaceuticals, and building materials.

The U.S.-affiliated islands of the Pacific include the Mariana, Caroline, and Marshall Islands in Micronesia and American Samoa in Polynesia. Together, they number more than 2,000 islands and atolls, but only about 100 are inhabited. Scattered across some 3 million square miles of ocean, the islands have a total land area of about 1,000 square miles, half of which is on three islands (Guam, Babelthuap, and Ponape).

The islands may be roughly classified either as high islands of volcanic origin or as low islands or atolls of biogenic origin. High islands are characterized by the presence of a greater diversity of ecosystems, including fringing reefs, barrier reefs, lagoons, estuaries, mangrove swamps, and marine lakes. Atolls generally have only lagoons surrounded by barrier reefs.

Nutrient input from terrestrial run-off is believed to account for greater productivity at high islands.

Each of the island groups is unique in history, language, culture, and politics. Far removed geographically from sources of development capital, the islands share a common need for economic development. Because of the limited land mass of the islands, the oceans must play a significant role in any economic development that is to occur. Development of non-food marine resources of the region would contribute to increased stability of island economies by reducing their dependence on import of both processed and unprocessed materials, by increasing employment opportunities for island residents, and by generating revenue through export of locally produced goods.

The purpose of this report is to review and assess the development potential of non-food marine resources of U.S. insular areas of the Pacific. Particular attention has been given to renewable natural resources which can be managed on a sustainable yield basis. This assessment is organized into three parts: 1) historical resource exploitation and management, from precontact economies to World War II; 2) contemporary resource exploitation and management, from World War II to the present; and 3) potential resource exploitation and management.

HISTORICAL RESOURCE EXPLOITATION AND MANAGEMENT

Before contact with Europeans, Pacific island cultures relied primarily upon the ocean for their food, transportation, recreation, and spiritual well-being. Island cultures reflected a variety of geographical, social, political, and economic conditions, but groups were traditionally, and by necessity, self-sufficient. Although access to certain resources led to some specialization and trade, the traditional system of marine tenure in the Pacific was associated with the subsistence economy (Eaton, 1985).

Despite great differences in language and culture among island populations, each group evolved over the millenia a distinctive set of traditions which reflect a keen awareness of local ecological relationships. Rights to exploit marine resources were limited to a group claiming exclusive use of an area of sea and carefully controlled by taboos to ensure a sustained yield (Johannes, 1977). Ownership or use of adjacent land was generally regarded as the basis of rights to the beach, reef, and sea. Outsiders were excluded or could use the area only with permission, usually after making some form of payment or gift (Eaton, 1985).

Magellan's landfall at Guam in the 16th century marked the beginning of an era of European exploration and exploitation in the Pacific. Consequent to contact with Europeans was the introduction of iron. More easily worked and more durable than traditional materials, iron quickly replaced natural products as the raw material for everything from fishhooks to adzes. European merchants and whalers exploited the high value islanders placed upon iron and other goods to entice them into bartering for, among other things, natural products of the islands and their surrounding seas.

As the value of land- and sea-based natural resources in the Pacific became recognized, countries of Western Europe strove for jurisdiction over island groups. Colonial rule weakened traditional authority as new political and religious institutions were imposed. Traditional tenure systems were modified or outlawed in favor of western concepts of ownership rights and practices. Thus, there evolved in many Pacific islands a dual system of tenure, which frequently resulted in a cancelling of authority, thereby allowing uncontrolled abuse of resources (Eaton, 1985; Pulea, 1985).

A summary of non-food marine resources exploited in Micronesia prior to World War II is presented in Table 1. Details of the historical utilization of these resources are given below.

Pearls and Mother-of-Pearl

Pearl shell, or mother-of-pearl, was one of the most important sources of raw material for the manufacture of fishing tackle in traditional systems (Thompson, 1945). Fishhooks, gorges, and trolling lures were shaped from nacre produced by several families of gastropods and bivalves. Because of its iridescence, mother-of-pearl was also harvested as a resource for producing ornamental items.

Chief among the non-food marine products in early trade were pearls and mother-of-pearl of shells of the bivalve Family Pteriidae. Although there are no accurate records of this trade in U.S.-affiliated islands, small-scale harvest of pearl shell began in Palau during the German administration (Smith, 1947). Such an industry was well-suited to the islands, because little equipment was necessary; divers collected the pearl oysters by hand.

Merchants eagerly sought pearl and mother-of-pearl for the European market

TABLE 1. Historical exploitation of non-food marine resources among U. S.-affiliated islands of the Pacific prior to World War II.

Resource	Harvest	Utilization
Pearls/Mother-of-Pearl	Traditional Commercial	Ornamental, fish hooks Jewelry
Trochus	Commercial	Buttons
Ornamental Shells	Traditional Commercial	Ornaments, shell money curios
Precious Corals	Commercial	Jewelry
Reef Corals	Traditional	Lime
Marine Turtles	Traditional Commercial	Ornaments, fish hooks Turtle shell
Mangroves	Traditional	Timber, fire wood

where these products were highly valued for jewelry, buttons for garments, and other ornamental objects. Because a money economy operated outside traditional systems, harvests of pearl shell were unmanaged and stocks were overexploited. The development of diving helmets further aggravated the problem, and by the 20th century, natural populations of pearl oysters were depleted throughout their Pacific range (Oliver, 1962).

During the Japanese mandate, four Japanese companies began to culture pearl oysters in Palau in the 1930s (Motoda, 1938). One of these companies purchased the black-lipped pearl oyster Pinctada margaritifera from Palauan divers for cultivation of pearls. The other three companies used pearl species introduced into Palau from other areas of the Pacific. Motoda (1938) reported that these companies were producing more of the gold-lipped pearl oyster Pinctada maxima, which they introduced, than any region in which natural populations of the species were exploited. However, pearl oyster culture operations were closed as World War II moved into the Pacific.

Trochus

Exhaustion of natural pearl oyster stocks and increasing demand for mother-of-pearl stimulated search for new resources. The commercial topshell Trochus niloticus was found to possess dense, firm nacre suitable for button material (Hedley, 1917; Nakajima, 1920). Because trochus grew rapidly and was found at shallow depths, an extensive fishery for this species developed.

Within a few years, topshell harvests began to decline in a pattern similar to that of pearl oysters. The Japanes administration attempted to sustain topshell populations at fairly constant levels of productivity in Palau by imposing regulations on the length of the harvest season and on the minimum size of shells that could be harvested (Motoda, 1938; McGowan, 1956, 1958).

By the 1920s, the declining populations of mother-of-pearl species and high market demand in fashion centers of Europe and North America prompted research into methods of improving productivity. Japanese scientists successfully transplanted topshells in the Caroline and Mariana Islands in the 1930s (Asano, 1937a, 1937b, 1937c). Truk was the only area that produced a commercial harvest before World War II suspended the fishery (McGowan, 1956).

Ornamental Shells

The shells of marine molluscs have been valued as ornamental objects since prehistoric times. Various cultures and societies have attributed powers of magic, religion, and virility to shells, as well as placing value on them as currency and curios (Dance, 1966; Abreu, 1979).

Marine shells generally were harvested as raw materials for the manufacture of tools, utensils, ornaments, and weapons in traditional island cultures. These items were sculptured by craftsmen using tools such as chisels and drills made of seashells and files of sea urchin spines (H. Kurashina, personal communication, May 1984).

Shells of giant clams (Family Tridacnidae) were fashioned into adzes used to hew canoes and housing materials. Various gastropod shells were used as scrapers for removing the peel from food crops such as taro or for grating coconut. Colorful species were worn as ornaments or fashioned into beads for jewelry (H. Kurashina, personal communication, May 1984).

When early European explorers returned home from the Pacific, they brought with them various colorful shells which piqued the interest of naturalists and wealthy collectors in their own societies. Shell collecting as a hobby reached a peak of popularity in Western Europe and the United States in the nineteenth century, when many extensive collections were assembled (Dance, 1966).

Because calcium carbonate is the major component of molluscan shells, they have had a number of industrial uses, primarily as constituents of fine pottery glazes, toothpaste, and poultry food (Wells, 1982).

Precious Corals

Highly treasured by man for millennia (Grigg, 1977), precious corals were first discovered in the Pacific near Japan in the early nineteenth century (Grigg, 1971, 1974). Since that time approximately 95% of the world harvest of precious corals has come from the Pacific (Grigg, 1974).

Precious corals are those species whose skeleton is hard and dense enough to be polished to a high luster suitable for jewelry manufacture. Historically, precious corals referred to the red corals of the genus *Corallium*. More recently, the term has been applied to white and pink varieties of *Corallium* as well as gold (*Gerardia*), bamboo (*Lepidisis* and *Acanella*), and black corals (*Antipathes*) from the western Pacific (Grigg, 1984).

With the exception of the black corals, precious corals inhabit deep water (100-1500 m). Therefore, harvest of these corals has been by means of dredges, or "coral mops", which break and entangle the coral (Grigg, 1971). Takahasi (1942) reported that *Corallium* of good quality was harvested off the southern coast of Peleliu Island in Palau and north of Pagan Island in the Marianas before World War II.

Other Non-food Resources

A variety of other non-food marine resources was harvested in the subsistence economies of the Pacific. Although marine turtles were caught primarily for food, turtle shell provided a resilient material for the manufacture of fishhooks and other items (McCoy, 1974). Among high islands, timber and leaves from various mangrove species were used in construction of dwellings and canoe houses. Shark teeth were incorporated in some weapons of war used by Micronesians. Experimental sponge culture by Japanese scientists in the Marshall Islands produced fine quality sponges, but commerical exploitation of the beds was prevented by war (Smith, 1947).

CONTEMPORARY RESOURCE EXPLOITATION AND MANAGEMENT

The end of World War II brought a new political order to the Western Pacific. The Japanese-mandated Caroline, Mariana, and Marshall Islands became a United Nations trusteeship administered by the U.S. as the Trust Territory of the Pacific Islands. Guam and the eastern Samoa Islands had already been acquired by the U.S. in the final years of the 19th century.

Pearls and Mother-of-pearl

Disrupted by war, harvest of pearls and mother-of-pearl never regained its place of importance in island economies. The culture methods developed by Japanese scientists in Palau before the war were regarded as proprietary information, and few islanders were permitted to observe the techniques of implanting pearl blanks (Smith, 1947). Without transfer of this technology, local inhabitants were unable to continue pearl culture operations, and the numbers of pearls produced by natural stocks of pearl oysters were not sufficient to support the industry.

Trochus

In the more urbanized district centers and ports, commercial exploitation of trochus resumed under U.S. administration. Because the war prevented commercial harvest, overexploited populations had recovered to some extent (Fig. 1), and harvests were greater in the years following the war than they were just prior to its outbreak (McGowan, 1956). However, populations began to

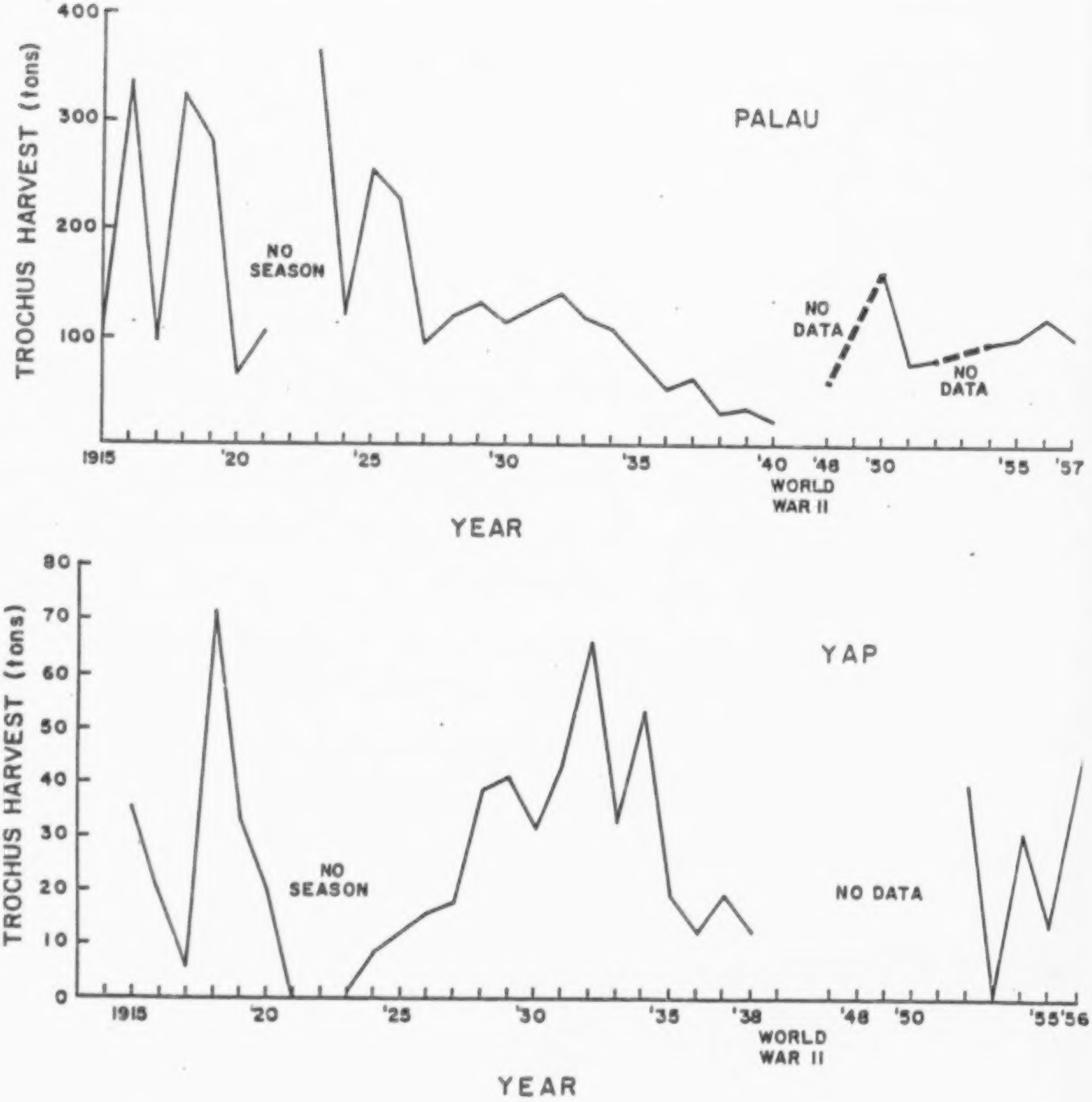

FIGURE 1. Commercial harvests of trochus shell in Palau and Yap, 1915 to 1957. After McGowan (1958).

decline again by the mid-1950s, leading to establishment of reef sanctuaries where no harvest was permitted (McGowan, 1958).

Records of harvests in Micronesia have not been well maintained over the years (R. Rechebei, personal communication, 4 August 1978), but steady increases in market prices in the last decade (Heslinga & Hillmann, 1981) have resulted in the trochus harvest becoming an important sector of island economy. It is a principal source of subsistence income, especially in remote areas, and as one of the few natural product exports, it is an important source of foreign exchange for island governments. Concern over sustaining this resource generated further studies on growth (Smith, 1979; Heslinga, 1982), reproduction and hatchery culture (Heslinga, 1980; Heslinga & Hillmann, 1981), and management practices (Heslinga et al., 1984).

Precious Corals

Because most precious corals inhabit depths beyond the range of scuba divers, detection of commercially harvestable aggregations has been a matter of chance. A two-man submersible developed to harvest precious corals in Hawaii (Grigg et al., 1973) overcame this problem to a certain extent, but it ceased operation after eight years (1971-1978) because of the combined effects of rising operational costs and a depressed coral market (Grigg, 1984). Most species of black coral occur in shallow water (30-70 m), enabling scuba divers to harvest them.

Although all known commercial concentrations of deepwater precious corals are found north of 19° N latitude (Grigg, 1984), their existence in Micronesia and throughout the South Pacific has been established (Grigg, 1975; Grigg & Eldredge, 1975; Grigg & Eade, 1981). While there has been no documented commercial harvest of deepwater corals in the U.S.-affiliated islands, there have been reports of Corallium collected in the waters of Palau (Takahashi,

1942) and the northern Mariana and Yap Islands (Anonymous, 1980a). Japanese and Taiwanese coral dredging vessels have also been sighted operating within the territorial sea of Palau and the northern Mariana Islands (Grigg, 1975; J. Villagomez, personal communication, May 1981).

Black corals, which are less dense, and therefore less valuable, than deepwater precious corals, occur throughout the Pacific. Occurring at depths which are within the range of scuba divers, black corals have been exploited on a small scale at Palau (Grigg, 1975), Guam (Hedlund, 1977), and American Samoa (personal observation, 1985). After being sawed off at its base by a diver, the coral is then cut or carved into jewelry or curios and polished to form the final product.

Harvest of precious corals in American Samoa and Guam is regulated by a fishery management plan under the Magnuson Fishery Conservation and Management Act of 1976. In other U.S.-affiliated islands, it is either governed by local laws or unregulated altogether. Enforcement of regulations is a difficult problem universally because of the vastness of the area involved and because of inadequate levels of funding and personnel for surveillance (Grigg, n. d.). Poaching of precious corals continues to be a major concern, even in waters under U. S. jurisdiction (Anonymous, 1986).

Ornamental Shells and Shellcraft

Following World War II the shell trade began rising in esteem again, not only with specialists and amateur collectors, but with tourists as well (Platt, 1949; Wells, 1982). Shells, shell jewelry, lampshades, and other shellcraft are highly prized by souvenir hunters at resorts throughout the world.

Shellcraft production depends upon an abundant supply of shells that is readily available to artisans. A cottage industry for shellcraft exists among U.S.-affiliated islands. It is generally limited to individuals who both produce and market their own handicrafts to the local tourist trade. Colorful shells are often incorporated as decoration in woven items such as baskets, fans, and mats. Engraving, shell carving, and shell inlay are not performed among the U.S.-flag islands.

Although most of the island governments have regulations on the harvest of edible or other commercially valuable shells, few have enacted protective measures for species involved in the ornamental shell trade. For example, on Guam the only legal action currently possible against shell collectors is veiled in vaguely worded sections on habitat destruction. Monitoring of the ornamental shell trade among U.S.-affiliated islands is nonexistent.

Specimen Shells and Corals

Specimen shells and corals refer to items prized for their individual appeal to collectors rather than for any decorative use. Depending upon the degree of sophistication involved, equipment requirements for the specimen trade may be as simple as a jar and a pair of gloves for shell collecting or hammer and chisel for coral collecting. Harvest of the more valuable species which inhabit deeper water requires additional equipment ranging from scuba gear and air compressors to dive boats and trap haulers (Parkinson, 1982).

Hedlund (1977) found that the shell collectors in Guam operate as individuals or as family units. Shells are marketed in local tourist shops or exported to dealers in other parts of the world. With one exception, a similar pattern occurs in the other U.S.-affiliated islands.

A cooperative specimen shell industry was initiated in Truk under government sponsorship in 1983 (Cane, 1984). Still in operation, the cooperative sells shells to local tourist businesses, but exports to outside markets have ceased because contacts with specimen shell dealers were not maintained by new management. However, it is deemed a successful operation by its founder and former manager because it demonstrated that the specimen shell trade can be a viable industry for this region (B. Cane, personal communication, 22 August 1985).

Although they constitute only a fraction of the value of precious corals, stony corals or Scleractinia make up the bulk of world coral trade. Too porous to be polished for jewelry, stony corals are sold as curios and decorations in many parts of the world (Grigg, 1984), and they are used industrially for building material, road construction, and lime production (Wells, 1981).

The major coral exporters in world trade are the Philippines and Taiwan. The genera _Fungia_, _Acropora_, _Pocillopora_, and _Porites_ contain the more popular species in coral trade. Non-scleractinian corals of the genera _Heliopora_, _Tubipora_, and _Millepora_ are often exploited as well (McManus, 1980; Wells, 1981).

In Micronesia, traditional harvest of coral to produce lime for the custom of chewing betelnut still exists in the Western Caroline Islands. However, most island governments have enacted legislation restricting harvest of coral for commercial purposes. As a result, there are a few small-scale coral specimen enterprises which cater to the tourist industry (Hedlund, 1977). There is currently no commercial export of specimen corals from the U.S.-affiliated islands.

Aquarium Fish

Colorful fishes from coral reefs are prized by aquarium hobbyists around the world. Several exotic species from the Pacific command high prices in the world market.

Fishing for the aquarium fish trade usually is a one-man operation. Small-mesh surround nets and dip nets are used to capture juvenile reef fish on the reef flat at low tide. The fisherman then either supplies the fish to a local pet store for retail sales or exports them to retailers in Hawaii or the mainland U.S. Some fishermen have provided contractual services for large aquariums in the business and tourism sectors.

On Guam, export operations in the aquarium fish trade have been relatively short-lived, except when the fisherman catches aquarium fish as a side-line to other activities. The major reasons given for these failures have been problems related to the airlines. Personnel handling airfreight do not regard live fish as requiring extra attention. Frequent flight delays aggravate already long distances and air times to large U.S. markets, resulting in losses of entire shipments valued at $200-300. Rates for air cargo from U.S.-affiliated islands are based on international schedules rather than domestic rates, making shipping expenses extremely high. One fisherman reported difficulties with a Honolulu-based buyer who regularly reported that all the rarer, and therefore higher-priced, species died in transit while lower-priced species all survived. Guam fishermen have not been successful at entering the potentially lucrative aquarium fish market in Japan because similar or identical species are available from the Philippine Islands at prices below the profitable margin on Guam (Richard K. Sakamoto, personal communication, 17 January 1986).

There is essentially no management of the aquarium fish trade per se. Fishermen on Guam must obtain a no-cost permit to use small-mesh nets, and there are certain area closures for aquarium fish collection (Anonymous, n. d.). However, enforcement has been sporadic because none of the government conservation officers is assigned exclusively to patrol reef areas. Therefore, it is a relatively simple matter to fish illegally with small-mesh nets.

The effects of the aquarium fish trade on stocks of reef fishes in Micronesia are not known. However, the degree of fishing pressure for food fishes on Guam's reef flats was found to decrease populations of some preferred species, permitting an undesired species to attain greater densities on heavily fished reefs than on lightly fished reefs (Katnik, 1982). Similar results could be expected if fishing pressures for aquarium species were to increase significantly.

Pharmaceuticals from Marine Natural Products

Many marine organisms produce compounds that are pharmaceutically active. For example, extracts of some brown algae have been used as hypotensive drugs in Oriental medicine for centuries (Baker, 1984). Neurotoxins from other algae are being studied for their potential as anesthetics (Curtin, 1985).

A number of new compounds have been identified from marine organisms from U.S.-affiliated insular areas (Schmitz et al., 1983; Gunasekera and Schmitz, 1983; Schmitz et al., 1984). However, there has been no systematic program to collect and screen marine organisms from this region. The competitive nature of this field of research has resulted in all efforts to date being disjunct projects by various individuals.

Phycocolloids

Phycocolloids are polysaccharide thickening agents produced by certain marine algae. Agar and carrageenan are phycocolloids which have important markets as commodity food additives, pharmaceuticals, cosmetics, paints, and ink. Other non-food products from marine algae include fodder for livestock and fertilizer (Waaland, 1981).

Of the numerous species of marine benthic algae reported from U.S.-affiliated islands, ten species may have the potential to yield harvestable commercial products (Tsuda, 1982). Two genera of the red algae or Rhodophyta have been studied for mariculture potential in Micronesia. The carrageenan-producing genus Eucheuma has been farmed successfully in Ponape

(Doty, 1981) and Kosrae (Mike White, personal communication, 21 August 1985) but no marketing has been conducted at this time.

The genus Gracilaria has been studied in some detail in the Mariana Islands. Gracilaria edulis from Guam produced higher yields of agar than similiar species from Taiwan (Nelson et al., 1983), where commercial cultivation of seaweeds began in the late 1950s (Tseng, 1981). Gracilaria lichenoides from Saipan produced agar with greater gel strengths, and therefore potentially more economic value, than species from Taiwan (Nelson et al., 1983). Nelson et al. (1980) found that Gracilaria grew rapidly in both the field and laboratory on Guam. A major obstacle encountered in efforts to culture these species in the field has been browsing by herbivorous reef fishes (Nelson and Tsutsui, 1982).

Sand and Quarry Material

Any level of urban and industrial development creates strong demands for mineral resources, including construction minerals such as sand, crushed stone, and fill. For example, a concrete foundation for a 10 m by 15 m house or office requires about 80 tons of aggregates (Dehais and Wallace, 1981).

Dredging of sand and fill materials has been conducted for projects involving airport expansion, road construction, and harbor development throughout the islands. Dredging in navigable waterways is under the jurisdiction of the U.S. Army Corps of Engineers (ACOE). All applications for dredging are routed through government agencies for review before permits are granted by ACOE.

Mining of intertidal beach sand for construction is regulated by local laws in some U.S.-affiliated islands and is under traditional jurisdiction in others. Currently there are no commercial ventures dredging sand from coastal waterways for cement manufacture.

Shark Products

Requiem sharks of the family Carcharinidae are abundant in waters of the U.S. Pacific insular areas. Uchida (1983) reported good catches of small reef sharks in fish traps, and Bryan (1972) demonstrated that commercial species could be caught on Guam with small boats. Although viewed as a nuisance by local fishermen, all parts of a shark theoretically can be utilized (King et al., 1984). Unfortunately, most of the potential value of the sharks is wasted, as fishermen usually take just the meat, fins, and jaws. Shark jaws and teeth are the primary non-food products now being harvested from sharks. They are used to produce novelties for the tourism industry.

Shark fishing methods do not differ from significantly from other commercials fishing methods. Probably the best method of shark fishing is longlining. A long line is stretched out with droplines or leaders spaced at regular intervals and with buoys attached to maintain the proper depth throughout its length. Gill nets are also used to catch sharks, but the initial expense of the net and the amount of time required for repairing it would make this method uneconomical among the islands.

Mangroves

Mangrove formations are highly productive ecosystems among the high islands of the Pacific. They are typically found in areas of low, muddy seashores, quiet bays, deltas, and estuaries. Characteristic vegetation consists of small trees of the families Rhizophoraceae, Meliaceae, and Verbenaceae.

Mangrove trees are economically important in subsistence economies of the Pacific as sources of structural timber and firewood. An extensive list of additional non-food products was reported by Lal (1984). They are also of great ecological importance because they provide food and shelter for a large and varied group of fish and shellfish (Odum and Johannes, 1975) and because they act as buffers for the prevention of coastal erosion (Baines, 1981).

Marine Turtles

The two most common marine turtles among U.S. insular areas of the Pacific are the green turtle and the hawksbill turtle. These ~~species~~ have been declared "threatened" and "endangered", respectively, and are protected under provisions of the U.S. Endangered Species Act. Therefore, all harvest of these turtles is prohibited in the territories of Guam, the Commonwealth of the Northern Mariana Islands, and American Samoa. However, residents of the other U.S.-affiliated islands are permitted to harvest marine turtles on a subsistence and traditional basis as a protein resource. Pritchard (1981) recently reviewed the status of marine turtle populations in Micronesia.

Although there is no visible handicraft industry based on the use of turtle shell, ornamental items can be purchased openly in many of the district centers (personal observation). Combs and bracelets of hawksbill turtle shell are especially popular among local inhabitants and tourists alike.

POTENTIAL RESOURCE EXPLOITATION AND MANAGEMENT

Many of the non-food marine resources of the U.S.-affiliated Pacific islands, such as pearl oysters and trochus, have histories of overexploitation resulting from poor resource management. Most of these resources have been underexploited since World War II because there has been little effort made to develop their potential (Table 2). Following is an account of those resources whose importance could be increased through improved research, development, and management.

Pearls and Mother-of-pearl

The success of Japanese entrepreneurs in Palau prior to World War II leads to obvious questions about why pearl culture has never been resumed in Micronesia. Several species of pearl oysters occur naturally in Palau (Motoda, 1938), Yap (Smith, 1978), Truk (Amesbury et al., 1979), Ponape (Mike Gawel, personal communication, 2 August 1985), and Guam (Smith, 1985). Surveys of some atolls in Ponape State found black-lipped pearl oysters in high densities (Mike Gawel, personal communication, 2 August 1985). The status of species introduced into pre-war Palau is not known.

Although attempts to mass culture pearl oysters in the laboratory have failed in French Polynesia, recent success with artificial spat collectors is expected to bring the harvest of wild stocks to an end by 1985, permitting recovery of natural populations (Coeroli et al., 1984). Technologies developed by Japanese scientists for grafting and implanting pearl nuclei (e. g., Mizuno, 1983) could be imported to the Central Pacific as they have been for French

TABLE 2. Status of non-food marine resource development among U. S.-flag territories of the Pacific.

Resource	Present Status	Potential
Pearls/Mother-of-Pearl	Underexploited	High
Trochus	Underexploited	Medium
Ornamental Shells/Shellcraft	Underexploited	Low
Precious Corals	Not exploited	Unknown
Specimen Shells/Corals	Underexploited	Medium
Aquarium Fishes	Underexploited	Medium
Pharmaceuticals	Underexploited	Low
Phycocolloids	Underexploited	High
Sand/Quarry Materials	Unknown	Unknown
Shark Products	Underexploited	High
Mangroves	Overexploited	Low
Marine Turtles	Overexploited	Low

Polynesia, where pearl exports in 1981 were valued at about US$3 million (Coeroli et al., 1984). The nacre of pearl oysters is more highly valued for button manufacture than trochus shell (William FitzGerald, personal communication, 18 April 1986), and the mother-of-pearl produced in a pearl culture industry would be an added value. Thus, the potential for pearl oyster cultivation in Micronesia and Samoa warrants further investigation.

Trochus

While trochus exports constitute a major source of income for island economies (Johannes, 1978; Heslinga and Hillmann, 1981; Carleton, 1984b), an examination of historical catch data indicates that the reefs are capable of sustaining far greater numbers of shells than are presently harvested. For example, the trochus harvest in Palau in 1916, 1918, and 1923 exceeded 300 tons (McGowan, 1958). Sharp declines in harvests immediately following those years indicate that such harvests amount to gross overexploitation (see Fig. 1). Parkinson (1980) estimated that Palau's reefs should yield sustainable harvests of some 200 tons/yr. However, the few records available for recent years indicate an average harvest of about 100 tons/yr (Ramon Rechebei, personal communication, 4 August 1978).

A comprehensive management and development program for trochus fisheries in the region might attain the figures given by Parkinson (1980). This would entail re-examination of sanctuary sites and stricter enforcement of size and season regulations (Heslinga et al., 1984). A ban on the use of scuba for trochus harvesting should be considered in areas where none exists (Johannes, 1978). An added measure to enhance yields would be a program of reseeding depleted reefs with hatchery-reared juveniles, similar to trout fishing enhancement programs in the U.S. Technology for mass culture of trochus has been developed at the Micronesian Mariculture Demonstration Center in Palau

(Heslinga and Hillmann, 1981) and is currently being transferred to Ponape (E. Flinn Curren, personal communication, 19 March 1985).

Attaining the sustainable harvests postulated by Parkinson (1980) for Palau, Truk, and Ponape would generate about 500 tons/yr, or about 14% of the world harvest (Carleton, 1984b) from these islands alone. These figures do not include harvests that will be realized from a trochus transplantation program initiated in Yap in 1983 (Karl Partridge, personal communication, 18 November 1983) nor the harvests of Kosrae and the Mariana and Marshall Islands.

Although the Samoas have been reported within the natural range for this species (Hedley, 1917; Motoda, 1938), no commercial trochus were sighted during a recent marine survey of American Samoan reefs (Smith, unpublished). The apparent eastern limit of their natural distribution lies in the Wallace and Futuna Islands, immediately west of the Samoas (Robert D. Gillette, personal communication, 11 March 1986). However, the presence of several noncommercial congeners of trochus in American Samoa (Smith, unpublished) indicates that suitable habitat exists for the commercial trochus. In light of efforts currently underway to transplant trochus to the Tokelau Islands, north of Samoa (Robert D. Gillette, personal communication, 11 March 1986), transplantation to American Samoa could be considered.

Although plastic buttons still dominate the clothing industry and their wholesale value dictates price levels for mother-of-pearl, pearl buttons hold a strong and high value sector of the consumer market (Carleton, 1984b). The price of raw trochus shell to the fisherman has increased from about US$0.2825/lb in 1978 (Richard Howell, personal communication, August 1978) to US$0.445/lb in 1985 (J. Robinson, personal communication, 6 August 1985). Thus, the value of the shell has risen some 57% in seven years. A button processing facility currently under construction by a Japanese firm in the Marshall Islands may contribute further to the economical importance of the trochus fishery in Micronesia (Peggy Buckingham, personal communication, 24 March 1986).

Ornamental Shells and Shellcraft

Ornamental shell industries already exist in some U.S.-affiliated islands, but most of the handicrafts sold in tourism centers are imported from the Philippines, where greater varieties of products are available at lower prices (Carleton, 1984a). Carleton (1984a, 1985) noted poor organization of handicraft industries in the Pacific. The major constraints identified were intermittent production and lack of business and financial advice to this sector of the economy. He noted that improvements in the production of handicrafts would increase the domestic value of the industry and provide greater market power. Therefore, efforts such as the Small Industries Center in Truk should be encouraged through government assistance.

Precious Corals

Little is known of the distribution and abundance of precious corals in Micronesia and Samoa (Anonymous, 1980). Most of the islands remain unsurveyed, and only preliminary data have been gathered in the Marianas and Palau (Grigg & Eldredge, 1975; Grigg, 1975). A recent survey of Pagan Island in the northern Marianas found dead specimens of precious corals but no live ones (L. G. Eldredge, personal communication, 26 February 1986). Poaching of precious corals by foreign coral vessels dredging near Micronesian islands provide further evidence of the existence of precious corals among the islands (J. Villagomez, personal communication, May 1981). Therefore, based on these reports and on the vastness of the Micronesian area, it is reasonable to assume that suitable habitat for precious corals exists in the region.

A temporary glut of precious corals depressed world markets after extensive new ground were discovered on seamounts near Midway in 1980 (Grigg, 1982). However, the continued decline of other stocks and the rapid depletion of the Midway beds combined to raise world trade in precious corals above US$50 million in 1982. Retail sales in Hawaii alone have averaged US$20 million annually (Grigg, 1984).

In 1981 the value of unprocessed deepwater precious corals ranged from US$72 to $4850/kg depending upon the species, color, and quality of the coral (Grigg, 1982). Thus, even small beds of precious corals could provide important revenues when harvested on a sustainable yield basis.

Black corals provide two alternatives for development among the islands. One option is to sell unprocessed corals to the industry in Southeast Asia. The other is to produce quality black coral products within the region. The latter alternative, which exists to some extent, is potentially more profitable, as it would create employment opportunities in the production, processing, and marketing sectors of the economy (Carleton, 1985). However, this course of action would require the acquistion of training and machinery for lapidary and jewel setting arts (Grigg, 1977).

Specimen Shells and Corals

The islands of Micronesia and American Samoa lie within the Indo-West Pacific region, which is characterized by having the most diverse marine fauna and flora in the world (Ekman, 1953). For this reason, Pacific islands are in a position to supply the specimen market with species of shells and corals that are not available from other sources. In addition, the islands would be supplying an expanding market (Carleton, 1984a). Bans on exports of corals and shells have resulted from reef destruction caused by overexploitation in some areas (McManus, 1980; Wells, 1981; Carleton, 1984a).

Although a certain degree of technical knowledge is required for the specimen trade, education programs have been developed for identification, selective harvest, and conservation of the resource (Parkinson, 1982; Cane, 1984). Grigg (1984) suggested that shallow water reef-building corals can be managed by using maximum sustainable yield models developed for commercial fisheries.

Islands remote from tourism centers would have have to rely on exports of specimens to dealers and retailers abroad (Cane, 1984). Although there are some reports that population densities of shells have decreased where tourism has developed, it is not clear if the reduction is caused by overexploitation or by increased runoff and pollution associated with urban development (Hedlund, 1977). Mass culture techniques developed for species such as giant clams, which have both food and non-food values, could be used to replenish depleted reefs (Munro and Heslinga, 1983; Heslinga and Peron, 1983; Heslinga et al., 1984; Heslinga, in press).

On Guam, a shell dealer who asked to remain anonymous indicated to me that his business is thriving. In addition to the many species he markets locally, he receives orders from specialists overseas who pay prices ranging from US$20 to $200 each for shells known only from the Marianas. He currently is filling an order for 45 specimens of a species that has a wholesale value of $25 each.

Aquarium Fish

Current supply does not satisfy demand in the aquarium fish trade, particularly in the U.S. Demand worldwide is expected to increase by 10-15% per year in the future (Carleton, 1985). Those islands with direct flights to Hawaii or Japan are suitably located to establish small aquarium fish businesses and take advantage of this situation.

When methods of collecting that do not damage the environment or harm nontarget species are used, small scale fisheries of this kind can be developed without upsetting the ecological balance on the reef. However, Johannes (1975, 1978, 1979) recommended bans on export of certain species which play vital roles in the health of coral reef communities. He cited evidence that reef fish populations can be drastically reduced when small fishes that remove parasites from other fishes were eliminated from the community.

Pharmaceuticals

Little economic reward can be expected to return to the islands as a result of novel natural products isolated from marine organisms from the region. Although some of these compounds have potential applications ranging from medicine to industry, their concentrations in the organisms are too low to permit detailed studies. Therefore, new products are quickly synthesized after their structure is identified, and any economic benefit derived from their development remains with the laboratory (S. G. Nelson, personal communication, August 1985).

Phycocolloids

The phycocolloid industry is expanding rapidly, and natural crops of seaweeds are not sufficient to satisfy the demand for gels (FAO, 1983). Because of the complexity of the polysaccharide molecules making up phycocolloids, prospects for synthesis of these compounds are not good. Therefore, farming of seaweeds, or marine agronomy, is an industry of considerable potential for the tropical Pacific. The value of the world phycocolloid industry was reported to be about US$1 billion in 1978, and gel extracts were estimated to be essential to some US$22 billion of the U.S. GNP (Doty, 1982).

The cultivation of seaweeds for phycocolloid extraction appears to be well suited for remote islands because little infrastructure is required. Algae are grown on shallow reefs, and the harvested thalli can be sun-dried and stored for long periods. The parallel to copra production, which has been practiced in the islands since the mid 1800s, is striking (Nelson et al., 1980).

The experimental efforts to cultivate seaweeds in the Central Pacific so far have met difficulties in marketing the dried seaweeds (S. G. Nelson, personal communication, August, 1985). This problem could be overcome by development of a gel extraction facility in one of the urban centers. The dried seaweeds could then be shipped from the production site for extraction, and the gels sold to industry.

Sand and Quarry Material

Except for a survey of Saipan, Tinian, Rota, and Pagan (Doan and Siegrist, 1979), the extent of deposits of sand and material for aggregates in nearshore waters of Micronesia and Samoa is not known. In the absence of such data, it is difficult to assess accurately the potential for development of these resources. Because islands have finite onshore mineral resources, the need to exploit marine deposits may arise in the future. However, the destruction of important fishing grounds and traditional fish pens has already occurred as a result of dredging and filling for airport expansion in the absence of thorough environmental assessments (Johannes, 1978; A. Edward, personal communication, September 1985). Therefore, environmental impacts of such operations must be rigorously assessed.

Shark Products

Sharks represent a potentially important and virtually unutilized resource in the tropical Pacific. In spite of the seeming abundance of sharks, Pacific islands supply only a small proportion of the market. Sharks are harvested primarily as a by-catch of Taiwanese tuna longliners landing at Pago Pago, and the fins are the only product that is retained (Carleton, 1985).

Presently unexploited among the U.S.-affiliated Pacific islands are shark hides, which are coming into prominence because they can be processed into beautifully grained, strong, scuff-proof leathers that are suitable for many applications (Anonymous, 1979; Slosser, 1983; King et al., 1984; Preston, 1984). Sharks that are 1.5 m or more in length are preferred for producing hides, but experience is required to decide whether a skin is worth taking and curing (Slosser, 1983). In addition, sharks that are harvested for skins must be treated differently than sharks caught for human consumption (Anonymous, 1980b; King et al., 1984). Therefore, establishment of a shark skin fishery in Micronesia and Samoa would require training programs for fishermen.

The value of shark livers, which have high concentrations of vitamin A, is currently low, except for livers with a squalene content of at least 80 percent. Such livers are found only in a few species of deepwater sharks which are not well known (Slosser, 1983).

Markets for shark products are expected to continue a recent trend of gradual expansion (Slosser, 1983; Carleton, 1985). Market growth, particularly for shark leather, appears to be limited by the supply of hides (Preston, 1984; Carleton, 1984). Novelty products such as jaws and teeth have a ready market in tourism, while new products such as artificial skin for burn victims (Anonymous, 1981) are still in the development stages.

Mangroves

The mangroves of the Caroline islands are more diverse and more extensive than those in other U.S. insular areas (Stemmermann, 1981). This abundance has led to speculation that some islands of Micronesia have sufficiently well developed mangrove forests to support small scale timber cutting industries

(Baines, 1981). However, Gillison (1981) urged caution on any expansion of harvesting activities in Palau and Ponape. He further emphasized a need for better resource data.

Cutting, clearing, and filling of the mangrove swamps should be carefully managed. In the absence of rehabilitation efforts, mangrove communities in clear-felled areas of Southeast Asia have not successfully regenerated. This lack of regard for the resource is tantamount to mining rather than harvesting on a sustainable basis (Baines, 1981).

The ecological importance of mangrove formations cannot be overemphasized. Mangrove swamps provide habitat for the young of many species of fish and shellfish. Fallen leaves of mangrove trees provide food for many animals in the swamp and out in the estuary as well. Roots of mangroves prevent coastal erosion by absorbing wave energy and protect coral reefs by trapping large quantities of sediments from terrestrial erosion. Mangrove communities also absorb dissolved nutrients from terrestrial run-off (Baines, 1981).

Marine Turtles

Commercial harvest of wild populations of marine turtles is prohibited under U.S. law. Thus, potential for exploitation of turtles lies with development of mass culture in turtle farms. A turtle hatchery is currently under development in Palau as a joint venture with Japanese scientists (S. G. Nelson, personal communication, September 1985). If this project is successful, it is conceivable that a limited amount of turtle shell and skin for leather could become available.

Another source of reptilian leather with limited potential for development is the marine crocodile of Palau. Like turtles, they are protected under U.S.

law, but farming techniques for crocodiles would probably be similar to those for turtles.

NEARSHORE ECOSYSTEM STRESS, RECOVERY, AND MANIPULATION

While tropical coastal ecosystems are among the most productive in the world (cf. Birkeland, 1985), they are also vulnerable to a number of natural and man-induced disruptions. Some theoretical aspects of this paradoxical vulnerability to disturbance in spite of high productivity and high standing crop on coral reefs were discussed by Grigg (1979). Because most of the nutrients in the system are accumulated in biomass, a high percentage is exposed to removal by exploitation. Thus, exploitation removes nutrients that would otherwise be recycled, and thereby reduces the potential for future production. Longevity of species exposes many year classes to exploitation, and long-lived species are generally characterized by low reproductive rates.

Because coral reef communities are disturbed by natural events at frequent intervals, the succession process is disrupted so often that few reefs develop a climax community (Connell, 1978). Further complications arise from interactions between natural and man-induced stress, which may be synergistic or super-imposed (Grigg, 1979).

Natural Stresses

Tropical cyclones or typhoons are frequent events in the Mariana and Central and Western Caroline Islands, but less common in the Eastern Carolines, Marshalls, and American Samoa (cf. Eldredge, 1983). High winds and rain cause destruction on land. Storm wave assault may cause coastal erosion, fragmentation of corals, slumping of reef framework, and abrasion and scouring of the reef. Structural damage to the reef framework was minimal after Typhoon

Pamela passed Guam in 1976, but damage to living coral and algal communities was intense and widespread on the deeper forereef slope zone (Randall and Eldredge, 1977).

Episodic catastrophes have also been related to tidal phenomena. Mass mortalities of reef animals have been studied on Guam (Yamaguchi, 1975) and at Eilat, Israel (Loya, 1976). In both instances, recovery of benthic communities was incomplete after three years. Rainstorms coinciding with spring low tides killed up to 92% of reef invertebrates at Enewetak Atoll, Marshall Islands (Leviten and Kohn, 1980).

Large scale biological disturbances have been generated on coral reefs by population explosions of the coral predator Acanthaster planci, or crown-of-thorns starfish. Initial outbreaks of Acanthaster are associated with high islands and are usually related to terrestrial runoff (Birkeland, 1982). Recovery of the coral communities requires about 10 years, but may be interrupted by secondary outbreaks (Colgan, 1981, 1982).

Other natural stresses are less common in Micronesia and Samoa. Although minor earthquakes are frequently recorded, the deep waters surrounding the islands preclude disruption by major tsunamis. Active volcanoes are limited to the northern Mariana Islands, where eruptions may cause severe disruption of intertidal and shallow-water habitats (Eldredge, 1983). The relationships between the El Nino phenomenon and shifts in rainfall and storm distribution in the central and western Pacific are still not understood well enough to determine cause and effect (Rasmusson, 1984).

Man-Induced Stresses

Urban development has generally concentrated in coastal areas of Pacific islands. As these areas attempt to transform from subsistence to more diversified economies, they are experiencing fundamental problems associated with population, commerce, light industry, and tourism (Low, 1981). Accompanying this transformation are unprecedented levels and kinds of waste discharges (Matos, 1981). Dahl and Baumgart (1983) reviewed pressures bearing on the Pacific environment, and a comprehensive report on tropical marine pollution was published by Wood and Johannes (1975).

Discharge of raw or primarily treated sewage and dredge spoils causes increased inputs of nutrients, turbidity, and sedimentation in coastal waters (Johannes, 1975). Organic or nutrient enrichment favors growth of decomposer communities, lowering dissolved oxygen levels to stressful levels. Turbidity and sedimentation physically degrade ecosystems through shading and smothering effects (Amesbury, 1982).

Because the tropical environment is near the upper tolerance limits of temperature for many reef organisms, thermal effluent discharged from power plants has disrupted reef communities in some areas (Jones and Randall, 1973; Neudecker, 1976). Thermal effluent could alter the pattern of succession on a reef by changing growth and survival ratios of reef species (Neudecker, 1982). Chlorine, used to control biofouling in power plants, is also very destructive in tropical ecosystems (Best et al., 1982).

Since oil is imported by means of tankers, there is some risk of oil spills. Small spills from port accidents, leaks in pipelines and storage tanks, and shipwrecks occur sporadically, but most have affected only small areas (Dahl and Baumgart, 1983). The effects of oil on corals was reviewed by Johannes (1975).

The marine environment cannot be separated from terrestrial influence. Toxic chemicals such as pesticides and herbicides used in agriculture enter coastal ecosystems via storm runoff. All the urban centers of the U.S. insular territories have storage areas containing polychlorinated biphenyl (PCB)-contaminated electrical transformers, and some of these storage facilities have reported leaks (Golob and Egan,1984). Japan developed a plan for low-level nuclear waste disposal in the deep ocean north of the Mariana Islands, but this proposal has been postponed as a result of protests from the Pacific community (Bacon et al., 1984).

Destructive harvesting practices such as the use of explosives and toxic substances have caused small-scale stresses in some areas. The use of dynamite is a commonplace but illegal practice in Micronesia (Johannes, 1975), and intense use of explosives has devastated some reefs (Parkinson, 1980; Naughton, 1985). Fishermen using dynamite are believed to have annihilated a damselfish species popular in the aquarium trade and endemic to Guam (Robert Saylor, personal communication, 11 February 1980). Long-term effects of explosives and toxic substances not only include loss of fish from the community and marked decreases of crustaceans, annelids, and molluscs, but the whole trophic structure may be altered by increases of other species (Campbell, 1977).

Concerns over man-induced stresses are growing. Marine communities in the tropics may respond differently to pollution than those at higher latitudes. Tolerance limits to many substances have not been determined. Heavy metals and many of the new synthetic compounds cannot be broken down in biological systems. As a result, some toxic substances accumulate in higher trophic levels of food webs. Contamination of ecosystems such as estuaries and the deep ocean is a particular concern, because their renewal rates are unknown.

Manipulation

Marine habitat rehabilitation or manipulation to increase production of desired resources has been largely conjecture (cf. Pinchot, 1974). However, mass culture techniques have been developed recently for some species such as trochus and giant clams (Heslinga and Hillmann, 1981; Heslinga, in press). Animals produced in hatcheries could be used to replenish overexploited reefs or to enhance natural production. Farming of giant clams in this manner has been compared to resource management in forestry (Yamaguchi, 1977). However, for trochus it would require a decision which could conceivably lead to reductions in populations of herbivorous reef fish as a result of depletion of algal standing crops. Although trochus has been widely introduced without obvious disruptions, no data are available on interactions between populations of large herbivorous snails and herbivous reef fishes. The work necessary to gather these data should be undertaken.

During the Vietnam conflict, mangroves were found to be especially sensitive to contamination with herbicides (Odum and Johannes, 1975). However, mangrove seedlings can be transplanted to sustain production in heavily exploited or disrupted areas. On Guam, a mangrove area damaged by an oil spill has been successfully rehabilitated through a replanting program (Bultitude and Strong, 1985). Mangrove trees killed by the oil discharge were removed, and the area was replanted with germinated seedlings that were harvested from an undisturbed area of the swamp.

The success of Japanese scientists in Micronesia during the mandate period suggests that a great deal of potential for economic development of marine resources is presently unrealized. In spite of recent advances in mass culture techniques, the basic knowledge remains unknown for many tropical species having potential for commercial harvest. Research on distribution, abundance, growth, reproduction, energetics, predator-prey interactions, and diseases will be required to develop sound management programs for optimum sustainable yield.

RESEARCH, EXTENSION, AND EDUCATION

Marine biological research in the U.S.-affiliated islands is centered at the University of Guam Marine Laboratory (UGML). This lab has a faculty of seven full-time researchers working in various fields within the discipline. Environmental impact studies, studies in aquaculture techniques and species potential, and resource assessment surveys have been performed by UGML personnel at various islands throughout the region. Cooperative research programs have been developed with Taiwan, Indonesia, and French Polynesia, and visiting scientists from around the world have conducted research at the facility. Contributions of the UGML are published in refereed international journals.

Additional marine research has been performed at the Micronesian Mariculture Demonstration Center (MMDC) in Palau. Although there are no resident scientists at MMDC, a number of important advances in mass culture of trochus and giant clams have been made by researchers visiting this lab.

Fisheries biologists of the U.S. National Marine Fisheries Service, Southwest Fisheries Center, Honolulu Laboratory conduct occasional resource surveys in the islands. However, their work has focused primarily on commerical food species, and there has been no overall continuity to their research.

Fisheries officers employed by local governments have also been involved in marine research. Generally these studies have been related to artificial reefs and resource assessments of edible marine organisms.

The only formal marine extension program in the U.S.-affiliated islands is the Sea Grant Extension Service at the UGML. This program is a cooperative project of the University of Hawaii Sea Grant College Program and the University of Guam. Staffed by a single agent, the program has concentrated on fisheries development, marine conservation, and public information and awareness. Sea Grant extension programs in Saipan and American Samoa have not been successful because agents were assigned to marine resources offices where public education programs were lower priorities than resource development (personal observation).

Local fisheries officers have been involved in extension efforts from time to time. A number of fishermen's training programs have been conducted through marine resources offices. If significant development of non-food marine resources is to occur, especially in the more remote islands, marine extension and advisory programs throughout the region will need to be strengthened.

Marine education programs are included in the curricula of the University of Guam (UOG) and several community colleges in the region. UOG offers undergraduate and graduate level instruction leading to Bachelor of Science and Master of Science degrees in biology. The graduate program in biology is taught by the faculty of the UGML and is decidely marine-oriented. The UOG faculty has also conducted workshops for high school science teachers to enable them to include marine topics in their curricula.

The College of the Northern Mariana Islands in Saipan and American Samoa Community College offer courses in marine science, but no degree program is available at these institutions. The Community College of Micronesia in Ponape has developed a two-year Associate of Science program in marine science that is primarily oriented toward fisheries personnel (S. James, personal communication, 10 July 1985).

SUMMARY: PROBLEMS AND OPPORTUNITIES

Considerable scope exists in the U.S.-affiliated Pacific islands for commercial development of non-food marine products. With markets for many of these products expanding, awareness of and interest in the resources is growing among the islands. Following is a summary of problems and opportunities to be encountered in developing sustainable economic benefits from exploitation of these resources.

Problems

1. Because of their geographical isolation, limited land area, small population, and finite natural resources, the Pacific islands have been neglected in regard to economic development. Exploitation of natural resources has been opportunitistic, involving export of raw materials or only the simplest of processed products.

2. Federal agencies with oversight responsibility for development of marine resources in the islands are not actually present. Instead, their representatives, usually based in Hawaii, make infrequent visits to the islands. They have little understanding, and frequently less concern, of the needs of the islands. Budget constraints are cited as the rationale for not having a greater presence in the islands.

3. Federal laws governing marine resources hinder their development in contrast to traditional laws which fostered wise management of the resources. Open access to resources in navigable waterways encourages overexploitation of any valuable products ("If I don't harvest it, someone else will").

Traditional marine tenure, however, required conservation and wise management of resources to ensure sustainable yields for the ownership group and to prevent overexploitation by outsiders.

4. Concise information on resource distribution and abundance is lacking. In the absence of such data, the concept of optimum sustainable yield is mere technical jargon. Historically, efforts to manage resources have been applied after it has already been overexploited.

5. There is no formal market structure for the non-food products of Pacific islands. Collection, analysis, and dissemination of market information and trends are absent. This usually means that the islands receive less than fair market value for their resources.

Opportunities

1. The technology for developing non-food resource industries already exists. Technological expertise developed in other regions could be imported to the Pacific islands and transferred to the islanders in a mode compatible with local lifestyles. Initially this would require government support, but with sufficient assistance, the islands could develop diversified, self-sustaining industries.

2. Development of the economic sector in remote islands through transfer of appropriate technology could help to reverse the trend of immigration to the urban centers. With limited land area of the islands, this must become a priority.

Recommendations

1. Provide technical expertise to the region. There is a strong need for creation of full-time positions in marine resource development and marine geology for the Pacific islands. Employed through the National Marine

Fisheries Service and the U.S. Geological Survey, respectively, these specialists should be associated with the University of Guam which is centrally located in the islands.

2. Earmark minority institution grant funds for the Pacific islands. Pacific islanders are, by definition, minority races. Therefore, they should receive minority assistance in education, extension, and research programs.

3. Establish regulations recognizing traditional marine tenure in the islands. To be successful, management schemes must be socially acceptable, and group ownership of marine areas has a long tradition. In addition, private investment in industries such as seaweed and giant clam farming, pearl culture, and even trochus fishing will require greater confidence in the chances for a reasonable return on investment, and marine tenure help can provide this.

4. Increase extension and advisory services in the islands. Federal matching funds should be made available through such programs as Sea Grant to establish marine extension agent positions in all district centers. Working closely with the islanders, the agents would transfer new and proven technical information from researchers to the harvest sector and facilitate research by relating problems encountered in the resource management sector to the appropriate researchers. To perform more efficiently, the extension agents should receive annual updates and training programs in technology and market developments. This effort could be coordinated on a regional basis through the University of Guam. The coordinator would be responsible for collection, analysis, and dissemination of this information through the extension network.

5. More baseline research on marine resources is needed. Many federal granting agencies restrict research proposals to short timeframes that are unrealistic for establishing a database, developing management models, and transferring technology to industry.

6. Develop the capacity for secondary industries to process raw materials

into commodities within the islands. Technology for processing non-food marine products exists, but capital for development of this sector is lacking. If Pacific islanders can produce quality products at reasonable prices, they could compete in the world market. Such development would greatly diversify and strengthen island economies.

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Background Paper No. 5

AQUACULTURE DEVELOPMENT IN THE U.S.-AFFILIATED ISLANDS

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

JAN 17 1986

AQUACULTURE DEVELOPMENT IN THE U.S.- AFFILIATED ISLANDS

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Revised, January 1986

ABSTRACT

Tropical aquaculture began in Asia and has developed into a widely applied system for producing food and providing income. Although suitable environments and aquatic species occur in South America, Africa and the oceanic islands, there has been no paralel development of aquaculture. However, with the currently available technology, there are opportunities for developing aquaculture in nearly all tropical and sub-tropical countries.

The following types of aquaculture are applicable to tropical environments and species of some of the U.S.-affiliated islands in the Pacific (American Samoa, Guam, Republic of the Northern Marianas, Republic of Belau, Federated States of Micronesia and the Republic of the Marshall Islands) and the Caribbean (The Commonwealth of Puerto Rico and the U.S. Virgin Islands):

Freshwater pond culture:

- Carps
- Catfish
- Crayfish
- Eels
- Freshwater prawns
- Ornamental fishes
- Tilapia

Saltwater pond culture:

- Marine shrimp
- Milkfish
- Mullet
- Red drum
- Tuna bait fish
- Turtles

Net pens or cages:

- Dolphinfish
- Groupers
- Rabbit fish
- Sea breams
- Sea perch
- Snappers

Inter tidal or sub-tidal culture on or off bottom:

- Clams
- Marine plants
- Mussels
- Oysters
- Pearl oysters
- Trochus

Most of these species are grown commercially at some locations in the tropics, but adaptive research may be required to test the applicability of culture systems to local environments and species. Culture of some species such as red drum, baitfish, dolphinfish, snappers and some clams will require research to provide a sound scientific base and reliable methodology.

INTRODUCTION

Aquaculture, the cultivation of aquatic organisms in fresh, brackish or marine waters began over 2000 years ago in China and developed into a widely accepted procedure for producing food in India, Malaysia, Indonesia, the Philippines and elsewhere in the tropical and subtropical regions of Southeast Asia. Although suitable tropical environments and aquatic species occur in South America and Africa, there was no parallel development of aquaculture in those regions. Even today, aquaculture is a far more important food-producing activity in Southeast Asia than elsewhere in the world.

There are opportunities in nearly all tropical and subtropical countries for increasing food production by developing aquaculture. This would require selection of species which are suitable for the local aquatic environment and which have been grown and marketed successfully in other areas. It also would require training of aquatic farmers.

The development of aquaculture in the Islands of the Tropical Pacific and the Caribbean is a special case because of the problems of finding adequate areas of suitable land, adequate fresh water, and productive sea water. Also the general logistical problems of supplying feed , equipment and supplies and transporting the products to the marketing areas could be limiting.

Tropical aquaculture is attractive because of the even climate which permits continuous growth of warm-water species such as shrimp, prawns and tilapia. However, these conditions may be unsatisfactory for temperate water species such as trout, salmon, and some oysters. Therefore species and site selection are extremely important in the planning of aquaculture developments.

The current study includes an analysis of the potential for the development of aquaculture in the U.S.-affiliated islands of the Pacific (American Samoa, Guam, Republic of the Northern Marianas, Republic of Belau, Federated States of Micronesia, and the Republic of the Marshall Islands) and the Caribbean (Puerto Rico and the U.S. Virgin Islands).

TECHNOLOGY ASSESSMENT

Several types of aquaculture or mariculture technology are applicable to fresh, brackish or marine waters in the tropics. As a general rule, lower technology systems sometimes described as "extensive or semi-intensive" are preferable to "intensive" systems in tropical areas because of the availability of low cost land, the suitability of the climate and the need to minimize capital expenditures and production costs.

For purposes of this discussion, the term "extensive" describes culture systems in which all of the nutritional requirements are derived from natural sources without conscious human intervention. "Semi-intensive" describes systems in which the carrying capacity is enhanced through intentional fertilization and/or supplemental feeding. "Intensive" describes systems in which all of the nutritional requirements are met from external sources. Various types of systems, the applicable species, the status of production technology and the required inputs are discussed in the following paragraphs:

Freshwater Pond Culture

Traditionally fish and shellfish in Southeast Asia were grown in large shallow ponds supplied with fresh or brackish water. The modern version of this system is a series of ponds from less than one to more than 50 acres each with a depth of two to three feet, supplied with fresh water at 10-50 gallons per minute (GPM) per acre from wells (bore holes), streams, or irrigation canals. Ideally the water should have a pH of 6.5-8.0, hardness of 50-300 ppm, alkalinity of 50-300 ppm, temperature of 24-32 degrees C. without contamination by pesticides or other chemical wastes.

Sites for construction of freshwater ponds should have flat or gently sloping land with soil of low permeability and without the acid sulfate condition which frequently occurs in mangrove swamps. About 1.3-1.5 acres of land is required for each acre of ponds. Farm sizes range from 1-5 acres of ponds for family enterprises to more than 100 acres for corporate ventures.

Freshwater ponds are used for growing various fish and crustaceans including freshwater prawns, tilapia, catfish, carp, ornamental fish, crawfish, etc.in monoculture or polyculture systems.

Freshwater Prawns

The freshwater prawn, Macrobrachium rosenbergii, known as the langostino in Latin America, is a native of Southeast Asia but is now grown in Hawaii, Honduras, Costa Rica, Ecuador, Mexico, Jamaica, Martinique, Guadeloupe, French Guiana, Puerto Rico, Israel, Taiwan, Guam, Solomons Islands (Nichols, 1985) and even in the continental United States.

The technology for rearing the larvae and juveniles in commercial systems was developed in Hawaii, beginning in 1965 and is currently used with some improvements in viable systems throughout the tropics. Several other species of Macrobrachium may have potential for aquaculture however, the large body of technical information concerning M. rosenbergii has made this the preferred species for commercial farms.

The major inputs for freshwater prawn farming include seed (postlarvae), feed (formulated pellets) and labor. Several commercial hatcheries produce postlarvae for sale to growers. However, it is usually more economical for farms of more than 50 acres to operate their own hatchery since seed can represent up to one third of the cost of production. Hatcheries require a source of salt water since the larvae need a salinity of 15-20 ppt. This can be supplied from the sea, from salinas, or from, saline wells. Improved hatchery technology makes it possible to recondition the brackish water used for larval culture so hatcheries no longer need to be located at the seashore.

The nutrition of prawns is supplied partially from the pond biota however at the densities required for commercial farms, it is necessary to supplement this with formulated pellet feeds containing about 23-30% protein. Prepared feed can represent more than 25% of the cost of production. An alternative is to maintain lower density of prawns so that a greater proportion of the nutrition can be supplied by the pond itself. However this requires addition of more organic or inorganic fertilizers to stimulate phytoplankton production.

Labor requirements of a prawn farm are similar to those of most farming operations. Unskilled workers can be trained to feed the prawns, maintain the ponds, and seine the ponds periodically to harvest the prawns. In addition, a small staff of well trained experts are needed to direct hatchery operations and to control water quality in the ponds.

Finally, the prawns must be harvested, processed, stored, distributed and marketed. In many places, freshwater prawns are marketed whole which simplifies processing.

Tilapia

More than 100 species of tilapia have been identified within the genera *Tilapia* and *Sarotherodon*, largely from tropical regions. Both genera are known as tilapia, black perch, African perch or freshwater perch and some red hybrids are marketed as cherry snapper. The two genera can be distinguished by their method of reproduction and their feeding habits. The Tilapia species are substrate spawners that guard the developing eggs and fry and are generally herbivorous. The Sarotherodon species are mouth-brooders which protect the fertilized embryos and fry by holding them within their mouths and are generally plankton feeders.

The species which have proven to be the most desirable for aqauaculture include *Sarotherodon niloticus*, *S. aureus*, *S. hornorum*, and hybrids of *S. hornorum* and *S. mossambicus* whose progeny are nearly all males with attractive red skin coloration. *S. niloticus* is usually the preferred species because of its rapid growth and efficient utilization of both natural and artificial foods which enable it to reach market size before starting to breed.

Tilapia are important as a staple food in many developing countries. They are generally cultured in simple earthen ponds similar to those used for freshwater prawns. Tilapia can be grown without supplemental feeding provided that the ponds are fertilized with animal manures, however production can be increased to more than 6,000 pounds per acre per year by stocking at high density and providing supplemental feed.

The major inputs for tilapia farming include seed (fry), feed, fertilizer and labor. The availability of seed is seldom a problem for tilapia farmers. In most cases, it is only necessary to stock a pond with fingerlings and wait for 3-4 months for them to mature and reproduce. A more serious problem is over-reproduction which will overstock the pond and result in large numbers of stunted fish. Several methods are now available for solving this problem. Predator fish may be planted in the ponds to eat the progeny of the tilapia. Another technique is to use monosex fry achieved by hybridization of appropriate species, or sex reversal to obtain all males by applying hormones during the early stages of development

The efficiency of tilapia culture on a commercial scale depends on establishing the natural biota which provides part of the food and supplementing this with artificial feeds containing about 20% protein. Tilapia can be grown at lower density in family or subsistence farms without supplemental feeds.

Tilapia are perhaps the easiest fish to grow in tropical aquaculture systems. They are extremely resistant to disease, withstand high density, tolerate low dissolved oxygen and other adverse environmental conditions.

The market for tilapia is well established in many tropical countries, however it is only recently that tilapia have become accepted in the United States and other countries in the temperate zone. About 15 companies are now raising tilapia in the continental United States but this usually requires special temperature controls to prevent high mortality during cold winters. Although their production is finding a ready market, it is unlikely that large scale tilapia farming will prove to be economical in the continental United States. In contrast, many areas in Latin America and the Caribbean Islands are ideally located for large scale culture of tilapia which might enter the world trade as frozen boneless fillets.

Catfish

The term catfish is used to describe several genera and species of fishes with barbels or feelers vaguely resembling the whiskers of a cat. Some species live in salt water or migrate between fresh and salt water, but those of most importance in aquaculture remain in fresh water throughout their life. Catfish are well acccepted as food in most countries, however, some religions have taboos against eating catfish because they lack scales.

A number of species are adaptable to aquaculture, but the most widely used in the United States is the channel catfish *Ictalurus punctatus*. This species readily adapts to crowded conditions in ponds, raceways, and cages, eats a wide variety of prepared feeds, and converts these efficiently into flesh. It is tolerant to handling and shipping, possesses excellent table qualities, and is a good recreational species. U.S. production exceeds 200 million pounds per year from more than 2000 farms in the southern part of the country.

Catfish are basically warm water species, however the channel catfish can withstand temperatures below 10 degrees C. This makes it posssible to grow this species in the temperate zone and also at higher elevations in the tropics.

Catfish grow and survive best at temperatures of 24-30 degrees C. and spawn at 21-29 degrees C. although lower seasonal temperatures improve spawning success. They prefer dissolved oxygen levels of at least 5 ppm. Although catfish are tolerant to a wide range of pH values, they generally prefer somewhat alkaline water with moderate hardness and alkalinity levels from about 100-300 ppm. The channel catfish is basically a freshwater species, however it has been cultured successfully in estuaries of the Gulf of Mexico at salinities up to about 8 ppt.

Catfish are usually raised in earthen ponds from less than two to more than 250 acres, however most commercial farms in the continental United States now use ponds of 15-25 acres. The ponds are stocked with about 3000 juveniles per acre which will yield about 3000 pounds at harvest at the end of the 210 day growing season. In the tropics, of course, catfish will continue to grow throughout the year so it is possible to selectively harvest those which are large enough for the market.

It is also possible to grow catfish in long narrow concrete tanks (raceways) supplied with large volumes of fresh water. Under these conditions, catfish can be held at densities exceeding 10 pounds per cubic foot of water. Such systems are used in the western part of the United States where warm water is available from geothermal wells. Similar systems might be used in the tropics in places where large quantities of fresh water are available, but where land suitable for ponds is limited.

The major inputs for catfish farming include seed, feed and labor. There are a number of commercial hatcheries producing fry and fingerlings in the United States which could provide the initial stocking of ponds. Thereafter, brood stock could be maintained in each area or at each farm to provide a continuing supply. Likewise satisfactory pelleted feeds are available from commercial suppliers in the United States and many other countries. However, the cost of shipping might increase production costs significantlly. Labor costs would be similar to those in pond culture of other species, however, mechanization of feeding and harvesting has reduced labor costs in efficient U.S.farms.

The U.S. market for catfish is large and expanding with current consumption estimated at over 200 million pounds per year. There is also significant domestic demand in most tropical countries. However catfish farming has developed as a low margin operation largely because of the necessity to compete with low cost imported catfish harvested from wild stocks in South America. Therefore product for export to U. S. must be produced at the cost of production in U.S less the cost of shipment, and handling.

Carps, etc.

The traditional aquaculture in China and Southeast Asia involves the planting of several compatible species in shallow earthen ponds, similar to those used for growing freshwater prawns, tilapia and catfish. These include the grass carp *Ctenopharyngodon idellus* which feeds on attached higher plants (macrophytes), the silver carp *Hypothalmichthys molitrix*, a phytoplankton feeder, the black carp *Mylopharyngodon piceus*, a snail eater, the mud carp *Cirrhinus molitorella* or the common carp *Cyprinus carpio* which are omnivores. In some tropical areas the polyculture species include the kissing gourami *Helostrama temmin-chi*, and catfish of the genera *Puntius* or *Clarias*.

Some or all of the above listed species may be useful in fish farms in tropical islands . All are hardy, feed at a low level in the food chain and are acceptable as food. The principal considerations in the selection of species of carp are the availability of seed, the area available for ponds and the local food preferences.

Ornamental fishes

Several hundred species or hybrids of freshwater or marine exotic fish are grown in home or public display aquariums in the United States. The total U.S. market for aquarium species and aquarium supplies reportedly exceeds $2 billion per year. Farmers in Florida, which represent as much as 95% of the U.S. tropical aquarium fish production, reportedly generate over $200 million in sales annually. Foreign freshwater tropicals, largely from Taiwan, Hong Kong, Thailand,Singapore and South America account for up to 40% of all tropicals sold in the United States.

The two main groups of ornamental fish are the egg layers and the live bearers, both of which are grown in the United States and also imported from foreign countries. The most popular egg layers are the angelfish, danios, gouramies and Corydoras catfish. Generally, egg layers are bred indoors in a series of aquarium tanks, where one breeder pair may produce thousnds of fry. In Florida, most growers move the juveniles to outdoor ponds at a length of 5-10 mm. However, they can be grown to market size (2.5-7.5 cm) in 3-6 months in indoor tanks.

Popular live bearers including the guppies, mollies, swordtails, platies, etc. are almost all hybrids. Live bearers which usually produce less than 300 offspring at a time are usually spawned and grown to marketable size in outdoor ponds in tropical areas. They can also be grown in indoor tanks, or large aquaria, but the profitability is questionable because of the slow growth of most live bearers.

With the tropical environment of Caribbean and Pacific Islands, it would be logical to raise freshwater live bearers in small shallow ponds similar to those used for the other species described above. Also there is potential for growing various species of marine tropical fishes for the aquarium trade. To be competitive, such ventures would require production and shipping costs below production costs in Florida and less than the cost of these species from other countries. In practice, most tropical aquarium farms raise several species and carefully select the best specimens for breeding purposes to maintain high quality of the product. This requires considerable expertise and strict procedures. However, this form of aquaculture is attractive because of the high value of the product , the short time required to reach market size and the small quantity of feed required.

Crayfish

The most successful crustacean aquaculture in the United States is based on the red swamp crayfish (crawfish), Procambarus clarkii. Approximately 50 million pounds are produced annually in the state of Louisiana on 105,000 acres of wetlands.

Crayfish usually live in swampy areas which may be flooded part of the year and dry at others but are grown in shallow ponds of 1 to 50 acres with 12-30 inches of water. They can tolerate slightly saline water (8.0 ppt) and do well in a pH range of 5.8-8.2 with hardness between 50 and 200 ppm. Under optimal conditions with plentiful food, crayfish may reach a market size of 15-20 per pound within 60-90 days in Louisiana. A brood produced in October will become sexually mature by the following July, and some as early as March (Conte, 1985 & 1985A).

The Louisiana crayfish growers do not use formulated feeds, but rather a detritus-based ecosystem in which the primary food is vegetative material that is broken down by bacterial action. Some production systems encourage growth of natural aquatic vegetation such as water primrose, smartweed, alligator weed and flooded sedges and grasses which provide forage and coverage. In other cases, growers plant crops such as millet or rice as forage for the crayfish.

The red swamp crayfish has been introduced in various countries including Kenya, Africa and in some cases has become established readily and is now the basis for aquaculture. There may be areas in the Caribbean or Pacific Islands which would be suitable for crayfish culture, however i;t is ujnlkiely that adequate areas are available for development of econoically viable commercial farms.

Saltwater pond culture

Traditionally, in southeast Asia and in some of the Pacific Islands such as Hawaii, marine or estuarine fish and some shellfish were grown in shallow coastal ponds which could be flooded at high tide. This concept, sometimes termed mariculture, has now been applied in many countries to provide low cost ponds for aquaculture of marine shrimp and various marine or brackishwater fishes. In some cases, the ponds are located slightly above high tide level to permit draining to facilitate harvesting the crop, however this requires pumping to fill the ponds.

Ponds for culture of saltwater species are similar to those used for freshwater species, ranging from two to four feet deep and from 1-30 acres. Large ponds are practical for species which are harvested by draining after a growth period of 3-6 months. Also, larger ponds are more economical to build than smaller ponds in areas where the land is nearly level.

Many of the earlier saltwater ponds which were built in mangrove swamps were found to be unusable because of the acidity of the water from the acid sulfate soil. This condition can be alleviated by continued flushing of the ponds with seawater and by planting vegetation on the dikes to prevent erosion. Alternatively, this problem can usually be avoided by constructing the ponds inshore of mangrove swamps, even though this requires pumping to fill the ponds. This alternative is often mmore desirable since it avoids the adverse environmental effects of destroying mangrove swamps which are important nursery areas for many species.

Sites for coastal farms should also have soil which is clay or other relatively impermeable type to reduce leakage.

Marine Shrimp

Shrimp have been cultured in primitive systems in Asia for at least five centuries by trapping wild juveniles and growing them in ponds, often with mullet or milkfish. Modern shrimp culture began in the 1960's in Japan when systems were developed for growing the larvae of Penaeus japonicus in hatcheries and rearing them to marketable size in ponds.

Shrimp culture began in the United States in the 1960's with attempts to apply the Japanese methodology to the three species found in the Gulf of Mexico. Most of these early commercial attempts were premature and companies found that they had to invest most of their funds in research and development rather than in production. Also earlier attempts to develop commercial shrimp farms in many other countries were largely unsuccessful because of inadequate technology, poor site seletion, high production costs, marketing problems and business management difficulties.

More recently, U.S. firms with local partners have begun marine shrimp culture in Ecuador and other Latin American countries using the local species Penaeus vannamei and P. stylirostris both of which are easier to grow than the species found in the Gulf of Mexico. The first farms depended entirely on seed (postlarvae and juveniles) captured in the channels among the mangrove swamps and stocked at low density in tidal ponds, some of which exceeded 50 acres, and grown without supplemental feeds. This system produced low yields of large-sized shrimp at very low prodution costs which found a ready market.

Subsequently, the culture technology was upgraded by increasing stocking and by providing supplemental feeds. This has greatly increased the production per unit of area and has led to a rapid expansion of shrimp farming in Ecuador, and other Latin American countries. However, further expansion will require hatcheries to provide the large numbers of postlarvae required since the harvest of seed from wildstocks has reached the maximum sustainable yield.

The commercial technology developed in Ecuador and Panama is now being applied (or planned) in commercial ventures in Peru, Colombia, Venezuela, Brazil, French Guiana,Jamaica, Antigua, Puerto Rico, Honduras, Costa Rica, Mexico, Dominican Republic, Hawaii, Guam and in Asia. There is also a resurgence of interest in marine shrimp farming in the continental United States using higher technology (intensive) systems

Tropical and subtropical shrimp grow best under the following conditions: water temperatures between 23 and 32 degrees C.; dissolved oxygen above 3 ppm; pH near 8.0 ; and salinity between 10 and 30 ppt. For best growth, adequate food must be provided for high-density culture systems, however, the shrimp may be kept at lower densities without supplemental feeds.

The most successful shrimp farms are located in the tropics where the natural climatic conditions permit year around growth. In such locations, extensive culture systems have been profitable although large areas,d usually 200-500 acres are required for corporate farms. Semi-intensive sytems with higher stocking rates and supplemental feeds are usually preferred for corporate ventures, however extensive systems are satisfactory for family or subsistence farms.

Major inputs for marine shrimp farms include seed, feed and labor. In areas where wild stocks of the species under cultivation are available, seed may be obtained by collecting juveniles in the estuaries. In other cases, postlarvae may be purchased from a commercial hatchery, but larger farms will require their own hatchery. If mature brood stock can be obtained from the sea, hatchery operations are relatively simple. If not, it would be necessary to maintain captive broodstock to obtain mature shrimp for reproduction.

The technology of broodstock maturation is developing slowly and although this can be accomplished at small scale, no successful farms depend entirely on maturation of captive broodstock at present. This has delayed the expansion of shrimp culture to otherwise suitable areas where no natural stocks of the culture species are found. The development of this technology will stimulate expansion of marine shrimp farming in the Caribbean Islands and possibly in the Pacific Islands.

Red drum

The red drum or redfish Sciaenops ocellata is a large marine fish of the family Sciaenidae which occurs from Laguna Madre, Texas to New York. It is usually found over sand and sandy mud bottoms in coastal waters and estuaries and feeds mainly on crustaceans, molluscs and fishes. Specimens reach a maximum length of 155 cm.commonly to 100 cm. The commercial and recreational fisheries occur throughout its range but especially off Texas and on the Atlantic coast south of Cape Hatteras.

Experimental work on the cultivation of this species, conducted largely in Texas has developed reliable methods for achieving maturation in captivity and growing the larvae. The first attempts at commercial culture began in 1983-4 and appear promising.

The redfish is attractive as an aquaculture species since it can tolerate salinities from nearly zero to more than 45 ppt. It can be grown in shallow ponds similar to those used for marine shrimp and prefers temperatures of 20-33 degree4s C. Although predaceous in nature, it can be conditioned to feed on formulated pellets with acceptable conversion ratios. The redfish is highly esteemed as a food fish especially at sizes up to about 13 pounds.

Juvenile redfish could be obtained from a commercial hatchery in Texas and raised to adults at the site selected for the culture operations to provide brood stock.

The economics of redfish culture in the islands of the Pacific and the Caribbean would depend largely on the availability and cost of feed and the cost of shipping the product to the United States since this species is virtually unknown in most of these areas.

Mullet

The grey or striped mullet, Mugil cephalus, is a prized food fish in Southeast Asia, Japan, the Pacific island nations and the Mediterranean basin. In the United States, it is at present, a major food fish only in the State of Hawaii. Mullet juveniles also represent an untapped resource of significant commercial value as live bait in the tuna fishing industry.

The expansion of mullet pond culture in Hawaii, as well as the realization of the bait potential, has been hampered, and in most cases precluded, by the limited availability of wild juveniles. Due to the capricious nature of the supply, long term efforts aimed at control of the reproductive cycle were carried out by the Oceanic Institute in Hawaii. These studies resulted in some success at laboratory scale in developing methods for spawning adults and rearing the larvae, however this methodology was not reliable enough for application at commercial scale. However, there are places in the tropics and sub-tropics where juvenile mullets can be collected for culture to market size in saltwater ponds. This form of aquaculutre is traditional in the Mediterranean basin. There is also the possibility that the technology will be improved to the point that commercial scale hatcheries would be practical.

The culture of juvenile mullet to market size in saltwater ponds is well developed and can be economical because mullet feed largely on the pond biota, requiring only fertilization.

Tuna Bait Fishes

Fisheries for skipjack tuna (*Katsuwonus pelamis*) requires large quantities of live bait to attract the schools to the vicinity of the fishing vessel so that they can be caught by feather jigs. The availability of bait fishes is the major factor limiting skipjack fishing by the pole and line method in the Pacific Islands.

Several species of small fishes have been grown in aquaculture systems for potential use as tuna bait. These include tilapia, (*Tilapia mossambica*) mollie or top minnow, (*Poecilia mexicana*) , milkfish, (*Chanos chanos*) mosquitofish (*Gambusia affinis*). Of these species, tilapia, mollies and mosquitofish are generally found in fresh water, but can also live in the sea.

The most extensive efforts to culture bait fishes have been in American Samoa with the mollies and in the Marshall Islands with milkfish. Results of the work in American Samoa and test fishing at sea showed that mollies are acceptable as live bait for skipjack and yellowfin tuna but uneconomical at the cost of rearing the mollies under experimental conditions (Bryan,1978 and Vergne,Bryan and Broadhead,1978).

The culture of milkfish for tuna bait began in 1972 when a lack of baitfish was identified as a constraint to the development of the skipjack tuna fishery in Kiribati. An experimental farm at Temaiku, South Tarawa, Kiribati began in 1973 and continued for more than a decade. Fishing tests in 1979 demonstrated that juvenile milkfish were acceptable bait for pole and line fishing for tuna.

By 1981, production from the 43 hectare farm was 32.6 metric tons, of which 20.9 mt was used for live bait and the rest for human food (Uwate, 1984).

An economic analysis of the project in 1983 indicated production costs of A$3.83-6.24/kg for baitfish which left little or no profit margin (PIDP, 1984)

There also is the possibilty of growing native marine species such as the nehu or anchovy, *Stolephorus purpureus* , the apagons, *Apagonidae*, and the white goby, *Glossogobins giurus* or other species which are captured in the lagoons by tuna fishermen. If the technology for culture of such native marine species could be developed, a stable aquaculture industry could be developed in many Islands of the Pacific and the dpole and line tuna fishery could be expanded.

Net Pens or Cages

A number of marine and estuarine fishes are grown commercially in floating cages or pens or in fixed enclosures in coastal areas. These include the yellowtail *Seriola quinqueradiata* and other species in Japan, Atlantic salmon *Salmo salar* and rainbow trout *Salmo irrideus* in Norway and now in Scotland, Canada and the United States, Pacific salmon *Oncorhynchus kisutch* and *O. tschawytscha* in the United States and Canada. In southeast Asia the milkfish *Chanos chanos*, tilapia *Tilapia and Sarotherodon* sps , the sea perch *Lates calcarifer* and groupers *Epinephelus* sps. are grown in similar systems (Huguenin and Ansuini,1978). Several tropical species discussed below might be grown in cages or enclosures in the Pacific or Caribbean islands.

Dolphinfishes

The dolphins or dolphinfishes, *Coryphaena hippurus* and *C. equiselis* known as mahi mahi in Hawaii and dorado in Latin America are high seas species which occur throughout most tropical and sub-tropical regions. Although the current study was to exclude deep water and highly migratory resources, the recent development of aquacuture methodology applicable in coastal areas has made it logical to include the dolphinfishes.

The two species of dolphinfish occur in the same general areas and may not be reported separately in catch statistics. They are similar in appearance but *C. equiselis* is higher in proportion to its length and reaches a maximum size of 75 cm. whereas *C. hippurus* reaches 200 cm.

C. hippurus which has been studied more than the smaller species, has several favorable characteristics for aquaculture. It is among the fastest growing fish and in captivity can gain 0.85-1.5 kg per month (Hagood et al.,1981 and Hassler,1977). This indicates that marketable fish can be produced in less than five months. Experiments at the Oceanic Institute in Hawaii indicated conversion ratios of about three to one using wet food such as frozen chopped squid and herring (Hagood et al., 1981), and they can also be fed on pelleted rations.

Methods for spawning the adults and rearing the larvae of both species have been developed at the Oceanic Institute in Hawaii and several generations have been produced. These studies have also shown that dolphinfish mature at about five months and spawn periodically in captivity which assures a dependable supply of eggs.

Field trials indicate good potential for growing dolphinfish in large floating net pens of cages similar to those used for growing salmon or trout in coastal areas. However, no commercial scale ventures have been attempted so the viability of dolphinfish culture has not been determined.

If cage culture proves to be economical, dolphinfish could be grown at hundreds of sites on the islands of the Pacific and the Caribbean. Since it occurs throughout the tropical seas, it is highly likely that aquaculture in the Islands would be technically feasible. The unknowns are the availability and cost of feeds, the feasibilty of operating local hatcheries and the logistics of supplying inputs and processing and marketing the products.

Groupers

Several species of Serranidae are grown commercially or for home use in enclosures or cages in southeast Asia. These include the green or estuary grouper Epinephelus tauvina or salmoides, the yellow grouper *E. awoara*, the mud grouper *E. brunneus*, and the red grouper *E. akaara*, (Chua, 1979 and Wu, 1985)).

Groupers occur throughout the tropical and sub-tropical seas and are well accepted as food. In most cases, there is little information or experience concerning the potential of these species for aquaculture. However, if the methods used in southeast Asia are applicable, local groupers could form the basis for mariculture in most island groups of the Pacific and Caribbean.

Caribbean species which appear to have acceptable characteristics for aquaculture include the Nassau grouper, *Epinephelus striatus* which lives in shallow water, reaches a large size and brings a high price on the market. Several other species occur in shallow water and might have potential for aquaculture in floating or fixed enclosures, (Glude, 1981).

The development of grouper culture would require a period of research to determine the applicability of the culture methods used in southeast Asia. Even then, the economics of commercial ventures would depend on the availability and cost of natural feeds such as scrap fishes and formulated pelleted feeds. Another potentially limiting factor is the availability of juveniles in nature which could be captured and grown to market size in the pens or cages. The technology for spawning adult grouper and rearing the larvae has been developed in southeast Asia but fry for commercial stocking are usually obtained from wild stocks. It is not known whether the culture methods used in southeast Asia are applicable to other species. Finally, the logistics of supplying inputs and processing and marketing the product would need to be evaluated.

Snappers, Sea Perch, Breams, Etc.

Several species of snappers, family Lutjanidae, the sea perch Lates calcarifer, the breams, family Sparidae, the rabbitfish, family Siganidae, and the milkfish Chanos chanos are grown in aquaculture systems in Asia. Fry for stocking commercial farms are generally obtained from wild stocks, but artificial propagation of the white sea bream Mylio berda has been achieved by the Hong Kong Department of Agriculture and Fisheries (Wu, 1985) In most cases, it is not known whether the methods used in southeast Asia are applicable to the culture of the same or similar species which occur elsewhere in the Pacific and Caribbean islands.

The methods used for culture of snappers, sea perch, breams, and rabbitfish are similar or identical to those used for growing groupers i.e. fixed enclosures or floating net pens in protected bays or estuaries along the coast. Milkfish are grown in the Philippines and elsewhere in fixed enclosures or in saltwater ponds.

A program of adaptive research is needed to determine the applicability of culture methods developed in southeast Asia to the islands of the Pacific and Caribbean. If successful, this would facilitate the development of family, cooperative and commercial aquaculture in many islands which lack adequate supplies of fresh water.

Intertidal or Sub-tidal culture on or near bottom

Sedentary species can be grown on bottom or suspended from racks or rafts in areas with adequate amounts of nutrients or suitable species of phytoplankton. Species grown in the tropics by these methods include oysters mostly *Crassostrea* sps., giant clams of the family *Tridacnidae* and mussels mostly of the genus *Perna*. In some areas marine plants (seaweeds) are grown for human food or as a source of phycocolloids (alginates, agar, and carrageenan), (Deboer, 1981).

Oysters

Native species of oysters are harvested for human food wherever they occur. Throughout Asia, oyster culture is a traditional form of aquculture. The methods now in use can be readily applied to expand oyster culture anywhere that the aquatic environment is satisfactory. In most cases native species can be used, however some of these are too small for the market.

In some cases, it is possible to introduce species of oysters from other areas, however this requires care in matching the local environment with the environmental requirements of the oysters. For example, temperate water oysters such as *Crassostrea gigas* from Japan are generally unsatisfactory for culture in the tropics because the constant warm temperature promotes continued spawning and therefore the oysters seldom are in marketable condition, (Glude,1984). A better alternative is to introduce acceptable species from a similar tropical environment. Transplanting of oysters from other locations should include procedures to avoid introduction of parasitews, diseases, predators, pests or competing species.

Oysters, like the other filter feeding molluscs, require substantial quantities of phytoplankton which in turn depend on nutrients carried to the sea by streams or carried to the surface by upwelling of nutrient- rich water from the deep oceans. Also most species of oysters prefer waters with salinity less than that of the high seas. These conditions occur in relatively few places in the tropical islands so the potential for mollusc culture in the tropics is not as great as in the temperate zone. Nevertheless, oysters occur in isolated locations, especially in the larger mountainous islands and these areas may have considerable potential for development of family, collective or commercial oyster farms.

The native species in the Pacific islands includes the widespread mangrove oyster *Crassostrea glomerata* (also known as genus *Ostrea, Saxostrea, or Saccostrea* and species *commercialis or cucullata*), the giant rock oyster *Crassostrea echinata* and the pink or coral oyster *Crassostrea mordax* (also known as genus *Ostrea, Saccostrea, or Saxostrea* and species *amasa, tuberculata, or cucullata*). In addition, the Philippine oyster *Crassostrea iredalei* has been experimentally introduced into other Pacific islands with some success, (Glude, 1984)

The principal native species in the Caribbean is the mangrove oyster *Crassostrea rhizophorae* which occurs throughout the Caribbean and along the Atlantic coast of Latin America. This species is collected from natural stocks and in a few places is grown in aquacultural systems.

The inputs are relatively simple since oysters obtain their own feed from the water. Also, in places where the native species is used, it is usually possible to collect seed (spat) by placing suitable materials in the water at the right time of the year. Even if seed can not be collected from natural reproduction, it may be possible to produce seed in a local hatchery if the known technology for spawning and larval rearing is applicable to the species being grown. Some success in rearing the larvae of C. echinata has been reported by the French research group at Tahiti (Coeroli,et al., 1984)

The establishment of oyster farms requires careful site selection and preferably pilot scale tests. Also the method of culture will depend on the suitability of the substrate, the exposure to storms, and other biological factors. In some places, off-bottom culture is used to avoid predators and to increase growth rate. In this case the oysters can be suspended below fixed racks or floating rafts, (Glude, 1980).

Pearl Oysters

The black-lip pearl oyster Pinctada margaritifera of the family Pteriidae occurs throughout the tropical Pacific and is harvested for the shell and for pearls. The potential for farming pearl oysters using seed (spat) produced in hatcheries was investigated by the French research group based at Tahiti in 1976-1977 however, the attempts at artificial propagation were unsuccessful. Subsequently, practical methods were developed for collecting seed from natural reproduction in the Tuamoto Islands. Although 60% of the oysters used for implanting with beads to produce pearls are still obtained from wild stocks, the farming of pearl oysters is expanding and the black pearl industry is the second most important economic export activity in French Polynesia,(Coeroli et al., 1984).

Although three years are required to grow pearl oyster to the size necessary for the nucleus-insertion operation followed by two years to develop high-value pearls, there is potential for profitable farming of this species at various places in the Pacific Islands.

Clams

Clams of various species are harvested for food in most island groups, but there is little or no clam farming. In some places in the Pacific, clams of the genera *Tridacna* and *Hippopus* are collected and relaid on reefs close to villages where they will be readily available, but this transplanting is not usually for the purpose of growing the clams to usable size. Recent research on larval biology and cultivation methods conducted in the Palau Islands indicates potential for hatcheries which would provide the seed needed to establish farms for these species, (Fitt et al.,1984 and Heslinga et al.,1984)

Most clams, like oysters, require adequate supplies of phytoplankton so culture in the tropical islands is limited to certain areas with adequate nutrients to support populations of algae. However the *Tridacnidae* derive most or all of their nutrition from symbiiotic algal cells called zooxanthellae (*Symbiodinium microadriaticum*). These dinoflagellates reside in the exposed mantle region and release photosynthetically fixed carbohydrates into the tissues of the clams. Tridacnids may thus be termed "autotrophic"(self feeding) or "phototrophic" (fed by the sun). They are the only animals of this kind suitable for human food production (Heslinga and Perron, 1983). Because of this method of feeding, the giant clams can survive and grow rapidly on coral reefs with low populations of algae. In fact, results of research in Palau indicate that the Tridacnids are the fastest growing bivalve molluscs in existence and possess an astonishing capability for producing large quantities of edible meat with minimal inputs (Heslinga and Perron, 1983).

The technology for farming Tridacnid clams has not yet been fully developed or tested, but trial shipments of juveniles produced in a hatchery in Palau appear promising. Successful transplants have been made to Guam, Hawaii, Marshalls, Ponape, Yap and the U.S. mainland and requests have been received from government representatives in American Samoa, Mexico and the Caribbean region (Heslinga and Perron, 1983).

Clams require a suitable substrate and most can not be grown readily in off-bottom culture systems. Therefore clam farming of Tridacnids or other species of clams would require careful site selection. Nevertheless, there are isolated areas in the islands where clams might be grown in family, or collective ventures and contribute to local food supplies as well as income.

Mussels

The green mussel Perna viridis, a native of The Philippines and elsewhere in southeast Asia, has been planted in the Society Islands by the French research group at Tahiti and has grown and survived well in ponds receiving nutrient-rich water from small streams. Similar plantings were unsuccessful in lagoons and bays where the salinity was 34-36 ppt, temperature was 25-30 degrees C. and nutrients were low. Success was largely related to the amount of phytoplankton in the water as indicated by this experiment and the observation that much greater growth occurred during the rainy season when phytoplankton abundance peaks. However, the temperature and salinity stratification which occurs during the rainy season decreased survival, (Coeroli et al.,1984).

Test plantings of green mussel spat from Tahiti at several locations in Western Samoa had varying results. Those suspended below rafts in Apia Harbor grew slowly and failed to mature. Those held on trays and suspended below rafts at Safata Bay reached minimum marketable size of five cm.in about five months. Similar plantings in Asua Bay reached seven cm and became sexually mature in about five months. (Bell et al., 1983). These experiments indicate that green mussel culture has potential at selected sites in the Pacific islands.

Marine Plants

Marine plants or seaweeds are used for human or livestock food, crop manure, soil conditioners and as a raw material for various chemicals. In recent years, seaweeds have been used in the Western World primarily for their phycocolloids (alginates, agar, and carrageenan) although both *Eucheuma*. and *Gracilaria* are consumed directly in many areas. Agar and carrageenan are widely used in food, pharmaceutical, textile, cosmetic and other industries as suspending, thickening, stabilizing, and emulsifying agents. The principal sources of agar are *Gelidium* and *Gracilaria* largely from Japan and Taiwan whereas carrageenan is extracted from *Eucheuma* grown in the Philippines and other tropical countries (DeBoer, 1981)

The environmental requirements of *Eucheuma* include salinity of 35-40 ppt, temperature for optimum growth of 26-30 degrees C., water flow 0.2-2.0 knots, but in areas protected from storm damage, water depth from intertidal to 20 m , water high in phosphorus, nitrogen and iron, high solar radiation, infrequent severe storms, few if any herbivores and minimum variation in environmental conditions. Since the level of nutrients is usually low in the sea surrounding tropical islands, artificial fertilization would probably be required to ensure adequate growth.

It appears likely that various species of seaweeds could be grown commercially in many tropical islands for local food and for export however the economics of such ventures should be investigated. Production from the highly successful Eucheuma farms established in the Philippines in the late 1970's oversupplied the world delmand which resulted in a severe decrease in prices. This left most of the new farms in an uneconomical position.

Reportedly a commercial firm in New Zealand is planning to establish a 100 acre pilot scale seaweed farm in Tonga (South Pacific Commission, 1983).

(Insert Table 1)

AQUACULTURE DEVELOPMENT IN PACIFIC AND CARIBBEAN ISLANDS

This section will discuss the historical development of aquaculture, including mariculture, in the U.S. affiliated islands of the Pacific and the Caribbean, the needs and considerations for the development of aquaculture in both areas and the opportunities for regional and interregional cooperation in these efforts.

Historical Development

A primitive form of aquaculture, holding juvenile fish in coastal impoundments sometimes with supplemental feeds, was practiced traditionally in various island groups including Hawaii. The remnants of early fish traps and impoundments can be found in most islands, but few are currently in use.

Recent developments in aquaculture or mariculture have included sporadic attempts to grow various species at experimental level, few of which have resulted in continuing commercial ventures as indicated by the following summary:

American Samoa. -- Some native mangrove oysters, Crassostrea glomerata, occur in the protected estuaries, and are used for food. However the local variety is too small for commercial use and therefore no oyster farming has developed.

A public funded research and development program to grow baitfishes for the skipjack fishery was carried out during the 1970s. Although this work resulted in the development of commercially applicable culture methodology, baitfish culture did not continue after the termination of public support. However these techniques are now being used in the Fiji Islands to provide bait for commercial tuna fisheries (South Pacific Commission, 1983).

Guam. -- A number of experiments in the culture of freshwater prawns, tilapia, marine shrimp, eel, carp, rabbit fish, turtles, and marine plants have been conducted by the Guam Department of Agriculture and the University. The culmination of these efforts was the 1982 Guam Aquaculture Developmnet Plan (PIDP,1984). Also during this period about ten small farms were established for growing freshwater prawns, and several other aquatic species in polyculture systems with prawn production of less than 10,000 pounds.

Eel culture, attempted on an experimental level, had good results in 1973. In 1977, a private venture was started with an initial stocking of eels from South Carolina. Subsequent seed importations were from Taiwan, Hong Kong, and the People's Republic of China. By 1979, two operations were ongoing and exported most of their production live to Japan.

Milkfish were introduced and experimentally cultured in 1974. Local and near-by fry supplies were too unpredictable to support an operation and an export ban by the Philippine Government ccontributed to the shortage of fry. However one private farm was in operation at that time.

Experimental culture of freshwater prawns was initiated in 1974 and private farms received limited quantities of postlarvae from the Hawaii Department of Fish and Game. By 1982 the University of Guam set up a hatchery and provided technical support for one private hatchery and about ten small farms were growing freshwater prawns for the local market with total production of less than 10,000 pounds in 1982 (Stern and Ure, 1984). Most of these farms also grow several other aquatic species in polyculture systems.

Marine shrimp culture began in 1978 when a fresh water shortage prompted one eel farmer to fill a pond with ocean water and stock it with shrimp.

One private marine shrimp farm was built in 1982 to test the feasibility of various production systems, and produceed small quantities of product for the local market.

Tilapia introduction was attempted in 1954 but was unsuccessful. In 1974 the reddish-orange hybrid was introduced and commercial farms were in operation by 1979.

Soft shelled turtle culture was attempted in 1977 by a private entrepreneur, but the turtles escaped. A second individual later attempted turtle culture with seed stock from Taiwan and marketed the product in Hawaii for a short time.

The University of Guam investigated the culture of marine algae, carp, Southeast Asian catfish, mangrove crabs, and mullet but, of these species, only carp are now being grown.

The Commonwealth of the *Northern Marianas*. -- This area has no known aquaculture or mariculture activities.

Republic of Belau (Palau). -- The Micronesian Mariculture Demonstration Center, established in 1972, conducted research on the culture of algae, clams, milkfish, molly, mullet, oyster, prawn, rabbitfish, shrimp, trochus, and turtle. As a result of this work some low technology farming of the giant oyster Crassostrea echinata was developed and shucked oysters were sold in Koror and even shipped via air to Guam on an experimental basis. Scientists at MMDC successfully spawned and reared freshwater prawns, marine shrimp, rabbitfish, trochus and turtles.

Methods for culture of four of the six species of giant clams of the family Tridacnidae were developed and juveniles have been planted in the Palau Islands and in other groups. This technology is ready for widespread application but will require development of local hatcheries.

Federated States of Micronesia.- Few aquaculture activities are known in Yap, Truk, Kosrae or Ponape Islands although suitable areas are available for culture of various species. Experimental culture of the algae, Eucheuma, exists in Ponape and Kosrae and a private seaweed project was initiated in Ponape in 1983 with grants and loans totaling US$353,000 (PIDP,1984). Trochus culture is on trial in Ponape and Tridacna culture exists at Yap and Ponape and is planned for Truk and Kosrae.

Republic of the Marshall Islands.- Experimental culture of pearl oysters and sponges was attempted by a Japanese firm before World War 2 and results indicated a good potential for sponge culture. A two hectare farm for blue shrimp was proposed in 1983, but no current aquaculture activcities are known (PIDP, 1984)

Puerto Rico. -- Aquaculture in Puerto Rico includes a small oyster fishery and some low technology efforts to develop oyster farming based on research in the 1970s (Waters and Prinslow, 1975). The limited suitable area, mainly in Boqueron Harbor, preclude the development of a large oyster industry.

Tilapia (Sarotherodon mossambicus) were planted in Puerto Rico many years ago and now are found in most streams and lakes. One commercial venture based on this species was started in about 1980 but was unsuccessful because of a badly designed culture system. Research and development by the University of Puerto Rico has shown that tilapia culture with well-designed systems has much potential.

Freshwater prawn culture began in Puerto Rico about 1975 but the first commercial efforts were unsuccessful because of bad siting in the flood zone and the inadequate state of culture technology at that time. Currently one large commercial farm and several small farms produce freshwater prawns for the local market. There is much interest in expansion with export to U.S. or other markets.

U.S. Virgin Islands. -- An aquaculture project supported by public funding was conducted at St. Croix for about a decade but terminated in the early 1980s. This laboratory investigated the potential for aquaculture using nutrient-rich water from the deep oceans and developed culture systems, some of which appeared promising. Subsequently this facility was used by a corporation for a marine shrimp hatchery. At present the facility is closed but the corporation reportedly plans to relocate the shrimp hatchery in the Bahamas.

Discussion. -- The island groups in the Pacific and Caribbean are similar in climate, logistic problems, limited land and fresh water. In both geographical areas the islands range from low lying atolls to mountainous volcanic islands and from small islands such as Yap with about 50 square miles of land and a few hundred residents to Puerto Rico an area of 3435 square miles and a population of more than 3.5 million.

The islands are also similar in the lack of aquaculture development although this is varies with size and the availability of fresh water. Most of the smaller islands lack adequate level land with clay soil for construction of ponds and adequate fresh water for culture of freshwater species. Although seawater is plentiful, the cost of pumping could be prohibitive. The larger islands such as Guam and Puerto Rico have several established aquaculture ventures and potential for expansion. The problem of logistics occurs in nearly all island groups. In view of these constraints, it is not surprising that aquaculture in these islands not developed as rapidly as in Southeast Asia.

Potential for development of aquaculture

The potential for development of viable aquaculture varies with the physical characteristics of the Island groups, their location in relation to sources of inputs and markets, availability of suitable sites, cost of production, investment capital and quality of project management of project management.

The challenge is to select species and culture systems appropriate to the island environment. This should start with an evaluation of the local environment and an analysis of the economics of aquaculture ventures considering the cost of production and transport to market in comparison with the costs in other areas competing for the same markets. It should also include an evaluation of labor and energy requirements and the social acceptability of this activity in view of the land and water requirements. It is also important to evaluate the environmental impact of aquaculture projects.

In general, large scale freshwater pond culture is not applicable to the small low-lying islands because of the shortage of suitable level land and fresh water. Large scale saltwater pond systems are not applicable to these islands because of the shortage of suitable land and the cost of pumping seawater. Either of these systems might be used for small scale family or subsistence farms.

The culture of marine species in floating net pens or cages is appropriate for island groups which have estuaries or bays where the structures could be protected from storms and where space in the coastal zone could be obtained. This system is advantageous because it does not require pumping of seawater and has low initial costs.

Intertidal or sub-tidal culture of sedentary species on or off bottom is attractive but this is practical only where natural supplies of phytoplankton provide adequate nutrition for filter feeding molluscs. This generally occurs only in estuaries which receive nutrients from the land. The exception is farming of the giant clams of the family Tridacnidae which are able to provide their own feed with the help of symbiotic algae.

Although intensive culture systems could theoretically be applied in any location, it is improbable that such systems would prove to be economical on the small tropical islands of the Pacific or the Caribbean.

The potential for development of aquaculture of various species in the U.S.-affiliated islands are discussed below:

American Samoa: With an area of less than 100 square miles on three mountainous islands, this group has limited level land suitable for construction of ponds and little fresh water for culture of fresh water species. Also, the coast line is generally exposed to southeast trade winds except for two bays on the South coast, Pago Pago Harbor and Pala Lagoon.

The two major tuna canneries at Pago Pago provide a potential source of fish scraps or fish meal which could facilitate the culture of carnivorous fishes such as dolphinfish, groupers and snappers. However, the applicability of culture technology for these species should be tested before initiation of commercial ventures.

Natural populations of oysters, Crassostrea glomerata occur in Pala Lagoon, however most are too small for commercial use. Small oyster farms might be developed in this area using improved culture methods which would accelerate growth or by introducing strains of C. glomerata from other islands or Crassostrea iredalei from the Philippines.

Several native species of clams have potential for aquaculture: Gafrarium tumidum, G. tumidum, Lioconcha lorenziana , and several species of Tridacnidae. Hatchery and culture methods have not been developed for the first three species but methodology for the Tridacnid clams is available from work in the Palau Islands.

There also is potential for commercial scale production of tuna bait fishes based on the earlier work in American Samoa, however a complete feasibility study should be completed before investment.

Finally, there is potential for culture of various species of marine ornamental fishes for the aquarium trade with marketing channels through Hawaii. This will require adaptive research to verify the applicability of culture methods to the local environment and species.

Guam: Geographically, Guam is a high island of about 250 square miles in area with steep or vertical cliffs in many places and with a narrow beach area and continental shelf. The island is surrounded by a surf swept fringing reef with few areas of protected water. This precludes most forms of floating net pen culture except in Apra Harbor which is largely used as a naval base.

Therefore the potential for aquaculture is limited to freshwater or marine species which can be grown in ponds or tanks. These include marine shrimp, freshwater prawns, ornamental species, eels and various species of carp.

Marine shrimp culture, based on experience at the private test facility built in 1982, could be developed as a commercial venture if the economics are favorable.

Freshwater pond culture of eels, carps and freshwater prawns has been developed in Guam and could be expanded. In view of the limited availability of fresh water, this would require application of methodology to minimize water use by culturing several species in the same pond or by reconditioning and reusing the water.

Another possibility is the growing of freshwater or marine ornamental fishes for the U.S. aquarium trade.

Palau: This group includes over 300 islands, most of which are high with steep sides. The soil is thin and agriculture is practiced mainly on the large island of Babelthaup. In between the islands are hundreds of narrow channels and bays, many of which are relatively deep (20 to over 100 feet). The high islands provide protection from wind and waves, so the bays and channels are generally calm enough for anchoring rafts for oyster culture or floating net pens or cages for growing fish.

The abundance of protected areas and the availability of tuna scraps from the local fishery indicate the potential for growing dolphinfish, groupers, snappers or rabbit fish in floating net pens or fixed enclosures. This would require verifying the applicability of culture methods used elsewhere for dolphinfish and some groupers and snappers, however local experience with rabbitfish culture would provide a sound basis for culturing this species. Also an analysis of the economic feasibility of growing these species in Palau would be needed before investment.

There is some potential for growing marine shrimp or freshwater prawns on the island of Babelthaup since both Penaeus monodon and Macrobrachium rosenbergii occur in this area. Although suitable land is limited, small scale farms might be established for the local market and for air shipment to Guam.

Oyster culture, based on the native species Crassostrea echinata, has been established but could be expanded with improved culture techniques, logistics, quality control and business management.

The hatchery technology for several species of Tridacnid clams was developed by the Micronesian Mariculture Demonstration Center at Koror and has beeen applied to provide seed for restocking local reefs and for polanting elsewhere in Micronesia. Hatchery production could be expanded as a base for development of commercial scale farms operated by Palauan villages.

There is also potential for growing tuna bait fishes for the pole and line tuna fishery and marine ornamental fish for the U.S. aquarium trade.

Other U.S.-affiliated Pacific islands: This includes the Northern Marianas, Yap, Truk, Ponape, Kosrae, and the Marshall Islands all of which are small volcanic islands or atolls and have limited land and fresh water, difficult logistics, low populations and undeveloped infrastructure. Most of these islands have bays or lagoons which are protected from oceanic waves and which might be suitable for anchoring rafts or floating net pens or cages. All have an oceanic climate suitable for culture of tropical species and abundant areas of clean seawater of uniform salinity.

In such areas, aquaculture is limited to local or introduced marine species which occur locally or can be introduced and which obtain their own food or can be fed on locally available feeds. The culture of dolphinfish, groupers, snappers or rabbitfish would be technically feasible in those islands with protected waters, however the cost of importing formulated feeds might well make the farm uneconomical. Also the cost of processing and transportation to distant population centers might be limiting.

It appears, therefore, that most aquaculture developments in these islands should be directed toward products which could be sold locally or transported easily to export markets such as Tridacnid clams, pearl oysters, Trochus shells, tuna bait fishes or marine plants. In some places, it may be economical to grow dolphinfish, groupers, snappers or rabbitfish if fish, not used for human consumption, or fish scraps are available. Also in some of the islands such as Ponape, fresh water may be adequate for small scale farming of local or introduced species of freshwater prawns.

Puerto Rico: This large mountainous island with 3.5 million persons, 3435 square miles of land and abundant fresh water has excellent potential for aquaculture. The broad coastal plain, used formerly for farming of sugar cane, is largely available for freshwater aquaculture.

In addition, Puerto Rico has a extensive shoreline of nearly 300 miles with numerous inlets and small bays which provide protected waters which may be suitable for anchoring floating pens or cages for culture of dolphinfish, groupers or snappers. Culture of one or more of these species appears to be appropriate for Puerto Rico, however this would require adaptive research to determine the applicability of methodology used in Southeast Asia and elsewhere and a feasibility study to project profitability.

Oysters occur in several coastal bays and are harvested commercially, but there are opportunities for expansion by applying methods used elsewhere. Although the suitable areas are limited, several small scale oyster farms could be developed to supply the local market. This would require the application of known techniques to increase growth rate and maximum size to produce oysters which would be large enough for the restaurant trade.

Commercial scale culture of freshwater prawns is already successful in Puerto Rico and could be expanded to provide additional product for export.

Tilapia are currently being grown in the University of Puerto Rico research station at Lajas and there is local interest in establishing private commercial farms. The product would find a substantial local market and could be exported to the mainland U.S. as frozen boneless fillets. However, the economics of tilapia farming have not been proven by commercial experience in Puerto Rico.

There is also potential for farming marine shrimp, however few large coastal tracts of land are available. Therefore, to be competitive with farms in Ecuador, it would be necessary to produce significantly higher quantities per unit of area and to minimize production costs. Also shrimp farms would need to include hatcheries with facilities for maturation of brood stock since no wild-stocks of _Penaeus vannamei or P. stylirostris_ occur in this area. Finally since marine shrimp culture has not been tried in Puerto Rico, adaptive research and pilot scale tests to determine the applicability of Latin American technology would be advisable.

Other species with untested potential for commercial aquaculture include the red drum, the queen conch Strombus gigas, and marine plants.

U.S. Virgin Islands: This group includes about 50 square miles of land on two large and several small islands with total population of less than 50,000. Geographically, these are low islands with little fresh water. Therefore aquaculture will be limited to marine species raised in the sea such as marine plants, queen conch, dolphinfish, groupers or snappers or in coastal ponds such as marine shrimp. Since none of these species has been grown in the Virgin Islands, a period of adaptive research and pilot scale testing would be needed to determine the applicability of culture methodology used elsewhere.

AQUACULTURE PROJECT INITIATION

The previous sections of this report have described the historical development of aquaculture in the subject island groups and discussed the potential for development or expansion of aquaculture in these islands. This section will discuss the steps required to initiate projects that will become viable commercial ventures or subsistence farms.

Requirements of the Entrepreneur -- Operators of aquatic farms are of two general types: (1) local residents who wish to provide food or increase their income by raising fish or shellfish and (2) individuals, partnerships or corporations who plan to develop commercial scale farms for profit. The first type of entrepreneur needs ambition and a real interest in farming and must be willing to work long hours and minimize production costs. He needs a simple, thoroughly proven, low-capital-cost system for growing the selected species. He also needs readily available low-cost inputs such as feed and labor and a local market for the products.

The second type of entrepreneur needs ability in business and financial management, a well developed business plan based on a thorough feasibility study, adequate financing, enough land at acceptable cost, identified markets, and adequate technical staff with experience in the culture of the selected species..

Requirements of Project Start-up -- Every project should begin with a feasibility study to evaluate the culture technology, availability of seed, construcion and production costs, availability and cost of land, availability and cost of labor, political and legal structure, taxes, permit requirements, local and export markets to provid an estimate the profitability of the proposed venture. A local resident probably would know about most of these factors, but an outside entrepreneur planning a large commercial venture would probably employ a consulting firm to do the feasibility study.

The second phase would be the development of a business plan that would include site selection, detailed engineering studies to estimate construction costs, production and production cost estimates, a marketing plan, development of requirements for financing start-up operations, staffing patterns, and profit and loss estimates.

The third phase would include capital formation, land acquisition, construction, staffing, purchase and stocking of seed and other activities common to the start-up operations.

Required Support Services -- Aquaculture development can be facilitated by government and academic activities and by local aquaculture associations. Foremost for the island groups is a recognition by government of the potential for aquaculture and the benefits to be derived. This ideally should take the form of a stated policy to promote and encourage the development of aquaculture and to provide technical and financial assistance where appropriate.

Government activities to facilitate aquaculture development could include an information and extension service to assist individuals in selecting apropriate species and sites and analyzing the feasibility of the proposed venture. Government could also assist by zoning suitable sites for aquaculture development and making such sites available to entrepreneurs at acceptable costs. Where lack of capital is a deterrent to aquaculture development, governments could provide low-cost long-term developmental loans or obligation guarantees. Finally, government agencies could help by expediting the process of obtaining permits and licenses required for production, processing and marketing.

Academic institutions could assist aquaculture development by conducting adaptive research to determine the applicability of culture technology used in other areas and by conducting research to solve problems encountered during production. In many cases it would be helpful for governments to support pilot scale tests and demonstrations of aquaculture systems conducted by local academic institutions.

When aquaculture has been established, the formation of local associations should be encouraged since these may assist in the exchange of information, group purchasing and cooperative marketing.

Common Problems of Start-up -- The primary problem is to develop a sound business plan based on a thorough understanding of the species to be grown, the state of culture technology, the suitability of the site selected, the cost of production and delivering the product to the consumer, the demand for the product and the possibilty of competition for the market.

The second major problem is to ensure adequate financing for the start-up period with a reasonable allowance for unforeseen delays or difficulties. Since the time from planting to harvesting can vary from 6 months to 4 years, the pay-back period for start-up loans should begin after the first or second crop is harvested.

The third major problem is delay beyond the projected time for achieving production which will provide a positive cash flow. A reasonable allowance for delays should be included in the business plan, but some delays such as difficulties in obtaining permits and licenses, are beyond the control of the entrepreneur. This situation usually requires refinancing.

Other problems include technical difficulties in applying the culture system to the selected site. This may require additional research to find a solution to the problem and perhaps a modification of the system. Such situations also contribute to the problem of accumulated delays during the start-up period.

Guidelines for Project Initiation -- The development and implementation of aquaculture ventures requires a wide variety of activities with many uncertainties. The major activities needed to ensure reasonable chances of success of a commercial scale farm are as follows:

1. Conduct a thorough feasibility study with consideration of culture technology, site selection, logistics, production costs, processing, distribution and marketing.
2. Develop a sound business plan with reasonable allowances for delays and unforeseen difficulties.
3. Acquire an acceptable site with room for expansion.
4. Arrange adequate financing through investors and through loans with acceptable pay-back periods.
5. Employ qualified technical and management staff and local laborers.
6. Maintain good working relations with government.
7. Maintain good public relations.

Potential for cooperation in aquaculture development. -- There are real advantages to be gained from cooperation between the U.S.-affiliated and the other (non-U.S.-affiliated) islands in both the Pacific and the Caribbean. This is partially accomplished in the Pacific through the South Pacific Fisheries Commission which facitates information exchange among the member nations, the Pacific Islands Development Program of the East West Center in Hawaii and the South Pacific Economic Commission. The Gulf and Carribbean Fisheries Institute and the new Caribbean Aquaculture Association perform a similar role for the Caribbean nations.

There are also advantages to establishing a mechanism to promote active cooperation between the U.S.-affiliated islands in the Pacific and the Caribbean. Since both rely on assistance from the United States, especially in technical areas, joint programs could be helpful.

Guidelines for Aquaculture Development on Small Islands

A study by the Food and Agriculture Organization of the United Nations in 1984 identified various factors contributing to the success or failure of aquaculture in developing countries (FAO, 1984). These are summarized in Table 2 as a guide for the development of aquaculture in the small islands of the Pacific and Caribbean. It is recommended that feasibility studies and proposals for aquaculture development projects include an evaluation of each of these factors and consideration of the environmental impact of any proposed project.

(Insert Table 2)

Constraints and Solutions

There are significant opportunities for aquaculture, in the islands of the Pacific and Caribbean in general and in the U.S.-affiliated islands in particular. These opportunities result from the favorable climate which permits year round growth of tropical species, the availability of clean seawater, and the need for food, employment and foreign trade.

The constraints include the availability of suitable land for construction of ponds, the limited supply of fresh water, the energy costs for pumping seawater, the low level of nutrients in the sea and the consequent lack of food for filter feeding species, the availability of protected bays and estuaries for pen, raft, or rack culture systems and the logistical problems of supplying inputs and distributing the products.

The technology for aquaculture of several species appropriate for the islands is available from developments in Asia and the United States, however research and pilot scale testing are needed before aquaculture of other species could be recommended.

Adequate planning with thorough feasibility studies are needed to select appropriate species and sites and to reduce the risk of new public programs or private ventures. Such planning studies should include socio-cultural and institutional factors which often have a major effect on the success or failure of aquaculture projects.

Congressional Action. -- It is clear from the foregoing analysis, that aquaculture has significant potential in the U.S.-affiliated islands, however, the progress in aquaculture development in these islands has been much slower than that in the temperate zone and in other tropical areas such as southeast Asia. Because of the physical and biological characteristics of the small islands, only certain kinds of aquaculture are practical, and some of these require a better base of scientific knowledge and practical experience than exists today. For example, it is not known whether the methods used in southeast Asia for culuture of marine fishes such as grouper or snapper are applicable in these islands.

Therefore it would be appropriate for congress to support programs of research and development which would provide a sound scientific base for the expansion of aquaculture in these and other island groups. It would also be appropriate to provide support for the training of local residents in aquaculture technology.

Federal Policies, Programs and Regulations. -- The Federal programs which usually apply also to the U.S.-affiliated islands are generally helpful to the development of aquaculture. However the administration of regulatory programs at the local level can cause long delays in the approval of permits and licenses needed for aquaculture ventures. Such programs, usually in cooperation with an insular agency, include coastal zoning, permits for introduction of exotic species, permits for discharge of effluent water, permits for drilling wells and use of ground water, etc.

Actions by Institutions to Facilitate Aquaculture Development. -- Actions at various levels are needed to encourage aquaculture or to mitigate the existing constraints as follows:

International Organizations. -- Technical assistance in feasibilty studies concerning aquaculture development has been provided by the Food and Agriculture Organization of the United Nations and by bilateral support programs of the European Economic Community and several donor countries and organizations. Such agencies also may facilitate aquaculture development by providing information exchange and statistical services. Generally, United Nations programs exclude the U.S.-affiliated islands.

Non-governmental international organizations which provide technical assisstance and information exchange include the East West Center in Hawaii and the International Center for Living Aquatic Resource Management in Manila.

U.S. Federal Government Agencies. -- Programs of these agencies are generally supportive. However, additional emphasis on research and development beyond the capabilities of the insular governments would expedite aquaculture development.

U.S. Congress. -- Congressional action to provide funding for expansion of research and pilot scale testing to ensure a sound scientific base would expedite the development of aquaculture in the islands.

Insular Governments. -- Information concerning aquaculture opportunities in each island group should be provided to insular governments to permit an informed choice of priorities for allocating available funds. Insular governments could expedite aquaculture by establishing policies to encourage this activity and by assisting potential aquaculturists in selecting sites and conducting feasibility studies and planning.

Private Industry. -- Potential aquaculturists could assist in the development of economically viable farms by adequate planning including marketing studies and feasibility studies and adequate funding of new ventures.

Academic Institutions. -- Research and pilot scale testing are needed to provide a sound scientific base for development of farms for some species. The logical roles of academic institutions are to provide such information and to train aquaculture scientists and operators of aquatic farms.

Non-profit Organizations. -- Such organizations could assist in aquaculture development by information dissemination, demonstration farms, and training of aquatic farmers.

Traditional, Indigenous Organizations. -- In some island groups, traditional village or tribal organizations fill the governmental role at the local level. In such cases, the development of aquaculture would be expedited by providing the village council or chief with information concerning aquaculture opportunities to ensure informed decisions regarding the allocation of land and water resources.

Benefits of Aquaculture Development.-- The development or expansion of aquaculture in the U.S.-affiliated islands would contribute significantly to local employment and in some cases, provide foreign exchange. These benefits, in total dollar value, would be greatest in Puerto Rico and Guam which have more land area, and least in the smaller islands or atolls. However, on a percentage basis, a small increase in employment or food supply in the smaller islands might be even more important than a large increase in the larger islands. This is especially true in those islands with few terrestrial resources, but with suitable coast lines for culture of marine species such as dolphinfish, groupers, snappers, bait fishes or giant clams.

TABLE 1 - ASSSESSMENT OF THE TECHNOLOGY FOR TROPICAL AQUACULTURE

CULTURE SYSTEM	APPLICABLE SPECIES	STATUS OF TECH. 1/	SUITABLE SITES	MAJOR INPUTS	ECOLOGICAL IMPACT
Freshwater ponds	Freshwater prawns	4	Inland, clay soil, adequate f.water. Can use land/water with salinity up to 8 ppt.	Seed, feed, labor, processing, mktg., capital for const. of ponds, hatchery, plant.	Non-consumptive use of water, effluent usable for irrigation, exotic species could escape.
	Tilapia	5	(Same)	(Same)	(Same)
	Catfish	4	(Same)	(Same)	(Same)
	Carp	5	Same, except require fresh water.	(Same)	(Same)
	Ornamental fishes	4	Same, except require fresh water.	(Same)	(Same)
	Crayfish	4	(Same)	Forage crops, harvesting labor, processing, mktg.	Utilizes swampy areas, exotic species could escape.
Saltwater ponds	Marine shrimp	3	Coastal land, clay soil, clean seawater. Can use land unsuitable for agriculture	Seed, feed, labor, processing, mktg., capital for const. of ponds, hatchery, & plant.	Effluent would supply nutrients to the sea, but could contaminate agricultural land with salt.
	Red drum	2	(Same)	(Same)	(Same)
	Mullet	4	(Same)	Same, except hatchery technology is not ready.	(Same)
	Tuna baitfish	1	(Same)	Same, except hatchery technology is is not ready.	(Same)

TABLE 1 - (Continued)

Floating net pens or cages	Dolphinfish	2	Shallow coastal bays or estuaries protected from storms.	Seed, feed, labor, processing, mktg., capital for const. of pens, hatchery & plant.	Requires permits for use of public waters. Pens could cause navigation problems.
	Groupers	3	(Same)	(Same)	(Same)
	Snappers, sea perch, breams, rabbitfish	1	(Same)	Same, except hatchery technology is not ready.	(Same)
Intertidal & subtidal culture on or near bottom	Oysters	5	Intertidal & shallow areas in bays or estuaries protected from storms.	Seed, labor, processing, mktg., capital for const. of racks or rafts, plant & possibly hatchery.	Requires permit for use of public waters. Rafts or racks could cause navigation problems.
	Pearl oysters	3	(Same)	Same, except hatchery technology is not ready	(Same)
	Clams	1	(Same)	Same, except hatchery technology is is not ready.	(Same)
	Mussels	3	(Same)	Same, except hatchery technology is is not ready.	(Same)
	Marine plants or seaweeds.	3	(Same)	Same, except hatchery is not needed.	(Same)

1/ Rating scale for the status of culture technology:
- 5 = Traditional system in common use. Economic viability widely demonstrated.
- 4 = Well developed technology in use for more than a decade. Economically viable is selected areas. Needs adaptive research to determine applicability to similar species or to other geographical areas.
- 3 = Recently developed technology applied in some commercial ventures. Economic viability not completely demonstrated. Needs adaptive research to determine applicability to similar species or to other geographical areas.
- 2 = Technology successful at pilot scale. Commercial ventures are in the planning stage.
- 1 = Some success in laboratory scale experiments. Needs research and development to provide a sound scientific base for commercial application.

TABLE 2

Major Factors Affecting the Development of Aquaculture

FACTOR	SUB-FACTOR	COMMENTS
ENVIRONMENT	PHYSICAL	Suitability of land and water (including quality and quantity) in relation to requirements of aquaculture species
	INSTITUTIONAL	Government policy, planning, programmes (such as training, extension services and financial assistance) and controls, legal requirements, political/economical stability
	SOCIAL	Infrastructure, stage of political development, traditions, life style, education of level
SPACE	LAND	Availability of space for aquaculture at acceptable cost
	WATER	Availability of space in lakes, bays, coastal zone for aquaculture at acceptable cost
TECHNOLOGY	CULTURE METHODOLOGY	State-of-the-art for growing selected species and local availability of methodology
	PRODUCT TECHNOLOGY	State-of-the-art of handling, preservation, processing, packaging, storage, distribution and local availability of methodology
PRODUCTION	PLANNING/MANAGEMENT	Business decisions re site selection, plant design, culture system, operations, capital formation and business management
	INPUTS	Availability of seed, feedwater, utilities and materials at acceptable costs
	OPERATIONS	Management, labour, and farm operations needed to grow selected species to marketable size
	COSTS	Fixed and operational costs in relation to revenues
MARKETING	PLANNING/MANAGEMENT	Decisions re product form, processing methods, marketing strategy and business management
	DEMAND	Domestic and export demand and prices
	OPERATIONS	Processing, preserving and packaging the products, distribution and quality control
	REVENUE	Market development, sale price in relation to production and marketing costs

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Background Paper No. 6

AQUACULTURE AND FISHERIES DEVELOPMENT IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

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Abstract

The nearshore fishing industry of Puerto Rico and the U.S. Virgin Islands is a multi-million dollar industry, producing excess of seven million pounds of seafood in 1982. In addition, nearshore resources have high aesthetic value and are an important component of the tourist industry. Major habitats include coral reefs, mangroves, and sea grass beds, many of which are threatened by development and exploitation patterns not consistent with sustained use. Harvest of traditional fishery resources typically approaches or exceeds maximum sustainable yield. Current use of nearshore resources is constrained by relatively small size of productive areas, multispecies nature of exploited stocks, ciguatera, and susceptibility to storm damage. Management systems are in place which, with modification, can significantly improve use of these resources.

Despite limitations, there are potentials for development of capture and culture fisheries which can significantly benefit the U.S. Caribbean territories. Recommendations for achieving these benefits include development of management plans for major nearshore ecosystems, limitation of harvest effort, support to local resource management initiatives, ciguatera research, and collaboration with other countries of the Lesser Antilles. Specific recommendations are provided for government agencies and private institutions.

Introduction

A. Significance to Economic Development

The fishing industry of Puerto Rico and the U.S. Virgin Islands produced more than 7.4 million pounds of seafood, and employed an estimated 2,450 fishermen in 1982 (Caribbean Fishery Management Council, 1984). Fin-fish accounted for about 85.7% of this production, and approximately 60% of all fin-fish landings in these islands are shallow-water reeffish which inhabit the area between the shoreline and the edge of the insular shelf where water depths exceed 70 m. Major shallow- water reeffish genera and species are listed in Appendix 3. The landed value of these species in 1982 totalled $8.7 million for Puerto Rico and the U.S. Virgin Islands combined. Though clearly significant as a million-dollar industry, this level of production falls far short of meeting the local demand for fresh seafood which has increased markedly with expanding tourism. Nearly 60 million pounds of seafood valued at $48 million are imported annually to Puerto Rico and the U.S. Virgin Islands (Caribbean Fishery Management Council, 1984).

Tuna account for the majority of fish landings in Puerto Rico (461 million pounds in 1983, including 143 million pounds caught in domestic waters; Herrick and Koplin, 1984). These and other migratory stocks are not discussed in detail, as they are specifically excluded by the task statement for this report.

In addition to providing an important source of food, nearshore marine resources are a vital part of the tourist industry: Coastal environments (beaches, sheltered lagoons, coral reefs) are among the islands' primary attractions. At least 1.8 million pounds of fish are landed annually by sport fisheries in Puerto Rico and the U.S. Virgin Islands (Clapp and Mayne, 1979; Caribbean Fishery Management Council, 1984).

B. Relevant Ecosystems, Species, and Capacities for Harvest and Culture

1. Ecosystems

Three major ecosystems are signficant to nearshore marine resources of Puerto Rico and the U.S. Virgin Islands.

a. Coral reefs -- Tropical oceans have been popularly characterized as "biological deserts", because nutrient levels are much lower than in temperate regions and primary biological production is correspondingly reduced. Continuing the analogy, coral reef areas) have been described as "oases of productivity" due to the level of biological activity made possible by organisms which increase available nutrients (e.g., algae which "fix" atmospheric nitrogen into forms useful to other species) and recycling of nutrients within these ecosystems. Coral reef systems are responsible for much of the nearshore fisheries potential of Puerto Rico and the U.S. Virgin Islands. The reef structure provides shelter for many species and surface areas upon which a variety of organisms grow and in turn become food for other reef dwellers. Coral reefs also serve as nursery areas for fish species which move into other habitats as adults. In addition to direct benefits to fisheries, some coral reefs provide natural breakwaters which protect shorelines from sea erosion. The variety in form and color characteristic of reef species is a well-known recreational attraction for residents and tourists alike.

b. Mangroves -- Like coral reefs, the spatial complexity of mangroves provides shelter, nursery areas, and growing surfaces for a variety of important species. The intricate root systems of mangroves act as a trap for sediment and land-derived detritus. Ninety-five percent of the annual mangrove leaf production eventually enters the aquatic system, and mangrove derived detritus accounts for 35 - 60 percent of suspended material in surrounding waters (Hanlon *et al*., 1975). This "provides an important nutrient base for food webs leading to commercially important food fishes and invertebrates" (Fell *et al*., 1984). These functions are not widely acknowledged, however, and mangroves are frequently destroyed in the process of "developing" waterfront areas. The Puerto Rico Coastal Management Program (U.S. Department of Commerce, 1978) states that three-quarters of the island's original mangroves have been destroyed.

c. Sea grass beds -- Some of the most valuable marine fishery species (e.g., queen conch and spiny lobster) are associated with sea grass beds for at least part of their life cycle. The leaves and interwoven roots provide extensive shelter for small organisms and grazing surfaces for a variety of species. Sea grass beds provide additional feeding areas for species on nearby reefs, and the variety of fishes tends to be higher on reefs close to these habitats.

It is important to recognize that these systems are often adjacent and mutually interactive. Mangroves, for example, trap sediment from terrestrial runoff which can be highly detrimental to coral reefs and sea grass beds. Similarly, coral reefs in some areas function as breakwaters which protect seagrass beds and mangroves from the full impact of sea waves. Nearshore fisheries may also depend upon a combination of these ecosystems. Larvae of spiny lobster, for example, commonly settle among the prop roots of mangroves, move onto adjacent sea grass beds or shallow reefs as juveniles, then into deeper reef habitats as they mature (Kanciruk, 1980).

2. Species

Six major species and groups of species are involved in the current harvest:

a. Shallow reef fisheries -- Most shallow-water bottom-dwelling fish in Puerto Rico and the U.S. Virgin Islands are associated with coral habitats. More than 300 fish species are found in these areas, of which about 180 are harvested for human consumption (cf. Appendix 3).

b. Deep reef fisheries -- Between 145 and 270 m snapper and grouper species are often found in areas where the slope is rocky or steeper than 30 degrees (Peacock, 1976). Groupers often occupy crevasses or holes, while snappers frequently congregate around outcrops. Both types of area can be difficult to fish, and deepwater demersal fisheries are generally thought to be underexploited in most of the Lesser Antilles.

c. Pelagic fisheries -- Population dynamics of pelagic fishes are not well understood, and the migratory tuna stocks which have received greatest attention (through the International Commission for the Conservation of Atlantic Tuna) are not considered nearshore species. Because most fishing effort has been directed to bottom-dwelling species (Caribbean Fishery Management Council, 1984) some increase in the harvest of nearshore pelagics is probably feasible, but the magnitude of permissible increase is not known. Shark resources are generally underutilized in the Lesser Antilles, but are particularly vulnerable to overexploitation because of low reproductive potential, slow growth rates, and greater age-at-maturity than other fishery stocks.

d. Spiny lobster -- Panulirus argus is the most highly valued fishery species in the Eastern Caribbean. This species has a long (6 months or more) larval life which makes it difficult to determine the origin of adult populations. Consequently, stocks in Puerto Rico and the U.S. Virgin Islands may depend upon production in other locales. As is the case with dolphin fisheries, this potential interdependence offers substantial justification for collaboration with other Lesser Antillean countries in developing marine resource management strategies.

e. Conch -- Queen conch (Strombus gigas) is the most important edible mollusc in the Eastern Caribbean. Because they are seldom found in depths exceeding 30 m, these stocks are highly vulnerable to overfishing. There have been several efforts to develop techniques for conch culture. Because post-larval conch require roughly three years to reach maturity, the grow-out phase is a serious problem for would-be culturists. A 1982 review of progress in conch mariculture (Berg, 1983) concluded that "commercialization of conch aquaculture does not seem economically feasible at this time." The prospect of "re-seeding" depleted areas with hatchery-produced conch requires pilot scale evaluation.

f. Other species -- In addition to the above groups, octopi (Octopus vulgaris), mangrove oysters (Crassostrea rhizophorae), top shells (Cittarium pica), and several other invertebrates are also harvested, but these species amount to less than 2% of total landings.

3. Capacities for harvest and culture

Harvest of nearshore marine resources takes place primarily in the vicinity of coral reefs and seagrass beds, though a few species are selectively taken from mangrove and rocky shore habitats. Because juvenile fishes are often found in these habitats and because adults of some species aggregate during spawning seasons, it is relatively easy to deplete many stocks. Fishing in breeding aggregations of Nassau grouper has resulted in the virtual annihilation of these populations in the U.S. Virgin Islands (Caribbean Fishery Management Council, 1984). Munro (1974) reported that in heavily exploited Jamaican fisheries, "negligible numbers of fishes survive long enough to spawn." Recent fishing effort targeted toward deep reef resources in Puerto Rico and the U.S. Virgin Islands may have significantly depleted these stocks, even though a relatively small number of vessels and fishermen were involved (A. E. Dammann, personal communication, June, 1985). Maintenance of populations under these conditions depends upon production elsewhere, and increased fishing effort in the latter areas is likely to lead to collapse of the fishery.

The fin fish harvest typically includes a variety of species, while the harvest of invertebrates is usually targeted

Table 1

Estimates of Sustainable Yield for Some Fishery Stocks of Puerto Rico and the U.S. Virgin Islands

Species or Species Group	Location	Shelf Area (sq km)	MSY (mt/yr)	Landings [Year] (mt)
Shallow-water reeffish	Puerto Rico	5538	2431 (1)	1489 [1982] (1)
	U.S.V.I.	1967	1038 (1)	1903 [1982] (1)
Spiny Lobster	Puerto Rico	5538	1418 (2)	15.4 [1978] (1)
	St. Thomas-St. John	1629	552 (2)	49.5 [1980] (1)
	St. Croix	343	193 (2)	
Conch	Puerto Rico	5538	562 (3)	1682 [1981] (4)
	St. Thomas-St. John	1629	165 (3)	not available
	St. Croix	343	27 (3)	26.8 [1979] (3)

Sources:

(1) CFMC, 1984
(2) CFMC, 1980
(3) Wood and Olsen, 1983
(4) Ballantine and Appledoorn, 1983

toward single species. In both cases, estimation of sustainable yields is problematic. Table 1 summarizes maximum sustainable yield (MSY) estimates for some stocks, but it is stressed that these estimates are liable to considerable error for reasons discussed below (section II.B). An MSY estimate in excess of current landings does not necessarily indicate underutilization because all landings are not reported, and because catches decline when MSY is exceeded. The latter circumstance indicates the need for information on catch per unit effort as well as MSY. Despite the uncertainty of yield estimates, available information and past experience suggest that development of these resources should proceed with caution.

As in other Caribbean islands, harvest and culture in the nearshore marine environments of Puerto Rico and the U.S. Virgin Islands are constrained by several features:

a. The physical size of productive areas is smaller than in other parts of the world where commercial fisheries have been developed. The continental shelf area of Puerto Rico and the U.S. Virgin Islands is less than 3000 sq mi (Caribbean Fishery Management Council, 1984), compared to the 76,000 sq mi shelf area of the Bahamas or the 175,000 sq mi shelf area of the Gulf of Mexico (Klima, 1976). In addition, highly productive habitats are not uniformly distributed over the entire shelf; their actual occurrence is typically less than half the total shelf area (e.g., Munro, 1977). Some stocks are confined to even smaller fractions of the shelf (e.g., deepwater snappers are most abundant on the shelf perimeter). The limited extent of highly productive areas is a particular constraint to culture of filter-feeding organisms (such as oysters or mussels) in natural waters (i.e., without fertilization).

b. The multispecies nature of most fishery stocks means that catches often contain a mixture of high-value and less desirable species. In fact, experience with the development of deep-water fisheries has shown that the proportion of less desirable species tends to rise with increasing exploitation (e.g., Vidaeus, 1970). Because the contribution of individual species to total production is relatively small, fishing operations targeted toward particular species may easily overexploit the resource.

c. The rugged topography of coral reefs makes it impossible to use towed gear (e.g., trawls) employed in many commercial fisheries. Aside from this difficulty, such gear is undesirable in reef and seagrass areas because of the inevitable damage to the productive habitats. Moreover, while such highly efficient non-selective gear is suitable in temperate waters, the limited resource base of tropical island fisheries cannot support this level of fishing effort.

d. Ciguatera (tropical fish poisoning not related to spoilage) poses a major obstacle to marketing fish in Puerto Rico and the U.S. Virgin Islands. Olsen and Wood (1983) state that 50% of the fish species landed (comprising 56% of the landings by weight) have been implicated in ciguatera poisoning. Large fishes (particularly snapper, grouper, kingfish and jacks) caught in depths less than 60 m are more likely to be toxic than other fishes. These species frequently constitute a significant portion of the fisheries potential in coastal areas, but cannot be sold due to the risk of poisoning.

e. Nearshore marine environments in the Caribbean are susceptible to damage by tropical storms; the Lesser Antilles have been subjected to four hurricanes in the past six years. These storms can alter coral reefs, seagrass beds, and shorelines overnight (e.g., Rogers _et al_., 1982; Woodley _et al_., 1981). Rogers (1985) points out that adverse impacts on fisheries due to habitat destruction are increasing, and that because reefs, mangroves and seagrass beds are interrelated, destruction of any of these habitats will adversely affect local fisheries. Potential storm damage to seawater ponds or cages is a constant risk faced by mariculture operations using these systems.

II. Fisheries Development and Management

A. Overview of Capture Fisheries

There is ample evidence that fishing played a significant part in the lives of Amerindians who inhabited the Caribbean islands prior to European settlers, though it is not possible to assess the relative importance of fishing compared to other activities. During the colonial period, fishing was never a major occupation (Suarez-Cabro and Rolon, 1974). Commercial fishery development in Puerto Rico began in 1941 under the Department of Agriculture, when the influx of military personnel substantially increased local demand for fish. This demand has been perpetuated by tourist hotels built to stimulate the economy. After the war, the program was transferred to the Puerto Rican Agricultural Development Corporation which emphasized offshore fisheries, and acquired a converted tuna clipper for experimental operations. The program terminated in 1947. Subsequent activities undertaken by the Division of Fish and Wildlife include establishment of fishing gear distribution centers, a fishery credit scheme, construction of facilities for gear storage and landing of fishing boats, and fishermen training.

Between 1974 and 1976 about 30 modern fiberglass fishing vessels (25 - 51 ft overall length) were introduced to the Puerto Rico fishing fleet. Twelve were acquired under programs of the Department of Agriculture, and the remainder by fishermen's associations through the Community Action Program of the Department of Labor (Juhl and Dammann, 1976). The objective of these acquisitions was to increase local fish production and to modernize traditional fisheries. Between 1976 and 1982, the number of fishermen in Puerto Rico increased from 1230 to 1872, while the number of fishing vessels rose from 865 to 1449 (Juhl and Dammann, 1976; Caribbean Fishery Management Council, 1984). This development pattern has had a striking impact on Puerto Rico's nearshore resources. Because of rising fuel costs, larger "offshore" boats have tended to fish closer to shore. In 1974 the waters of Puerto Rico were characterized as "very nearly overfished" and "heavily exploited" (Brody and Slocum quoted by Juhl and Dammann, 1976; Kawaguchi, 1974). The recent history of shallow-water reeffish landings illustrates the general trend. In 1975, the harvest from shallow reef areas in Puerto Rico was 3.25 million pounds; in 1980, landings from the same fisheries totalled about 4.15 million pounds. But the total effort expended within the fishery increased from 11,058 (standardized units based on catches from traps) in 1975 to more than 30,051 in 1980; catch per unit effort declined progressively during this period by more than 50%; a classic indication of overfishing (Caribbean Fishery Management Council, 1984).

Fisheries development efforts have been much less intensive in the U.S. Virgin Islands. But even modest increases in fishing effort coupled with technological innovations may have exceeded natural productive capacity. In 1970, the fishery stocks of the U.S. Virgin Islands were "not being endangered by overfishing" (Swingle, Dammann, and Yntema, 1970). Between 1970 and 1982 the number of fishermen in the U.S. Virgin Islands increased from 400 to 578, while the number of traps (which account for 70% of all fisheries landings) increased from 1041 in 1975 to 2588 in 1982. Between 1975 and 1979, catch per trap set increased by 78%, but declined by 27% between 1979 and 1982 (Caribbean Fishery Management Council, 1984).

Declining catch per unit effort has been accompanied by a rise is value of the catch. Between 1975 and 1982, the value of shallow-water reef fish landings in Puerto Rico increased from $1.149 million to 2.194 million; while the value of similar landings in the U.S. Virgin Islands increased from $1.223 million to $6.483 million. The difference is due to (a) an increase of 168% in actual landings in the U.S. Virgin Islands compared to less than 1% in Puerto Rico, and (b) a higher price per lb in the U.S. Virgin Islands (in 1982, $1.78 in the U.S. Virgin Islands compared to $0.77 in Puerto Rico).

B. Overview of Resource Management Technologies

As the above discussion would suggest, application of technology to manage nearshore marine resources of Puerto Rico and the U.S. Virgin Islands has not kept pace with development of technology for exploitation. Historically, these resources have not been regarded as highly important. Marine harvest activities have not played a central role in local societies, and informal or traditional regulatory systems have not developed (in contrast to island communities in the Pacific where marine resource use has been an integral societal element for generations).

Formal regulatory systems for marine resource management are relatively recent. The Fishery Conservation and Management Act of 1976 (PL 94-265) established a fishery conservation zone of 200 nautical miles within which the United States has exclusive management authority for fishery resources (except for highly migratory pelagic species). The Act also established eight Regional Fishery Management Councils which have the responsibility for developing management plans for exploited species or group of species) within their respective regions. The Caribbean Fishery Management Council has jurisdiction over Puerto Rico and the U.S. Virgin Islands, and has prepared management plans for spiny lobster and shallow-water reeffish fisheries. These plans place restrictions on types of gear which may be used for harvest, and establish minimum permissible sizes for harvested individuals of particular species. Other restrictions (e.g., closure of seasons or fishing areas) are also possible, but have not been enacted. Coastal Zone Management Programs have been prepared for Puerto Rico and the U.S. Virgin Islands as required by the Coastal Zone Management Act (PL 92-583), but contain no provisions directly relating to fishery management (Caribbean Fishery Management Council, 1984).

Puerto Rico has legal jurisdiction over fisheries within nine nautical miles of shore (in order to retain royalties from potential offshore petroleum development, the Commonwealth legislature petitioned the U.S. Congress for an increase to the customary 3-mile jurisdictional boundary, a request which was granted in 1980; Caribbean Fishery Management Council, 1984; M. Hernandez, personal communication, January, 1986). The Department of Natural Resources is responsible for fisheries regulation, while responsibility for management and development rests with a semi-autonomous agency (CODREMAR) associated with the Department. The U.S. Virgin Islands has fishery jurisdiction within three miles of shore. The Department of Commerce is responsible for fishery promotion, while all other fishery affairs are assigned to the Department of Conservation and Cultural Affairs. Fishery advisory committees are appointed by the Commissioners of both Departments.

While much of the legal and institutional capability is in place, management of nearshore resources is hampered by a basic lack of information on the resources to be managed. A formal statistical program for Puerto Rico fisheries was started in 1967 as part of the Commercial Fisheries Research and Development Program (PL 88-309), and a variety of activities were undertaken during the early 1970's through the College of the Virgin Islands to provide information needed for rational development of nearshore marine resources of the U.S. Virgin Islands. These efforts necessarily have been primarily concerned with characterizing the fishery sector in general, and understandably have not focussed upon specific resources within the sector. As a result, while essential preliminary information has been obtained, details for most species are not sufficient to permit the reliable estimates of sustainable yield and fishing effort essential to rational management and development.

C. Principal Factors Affecting Harvest and Management

Three factors have had a major effect upon harvest and management of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands:

1. Limited resource base -- The relatively small size of naturally productive marine areas means that the absolute magnitude of the potential harvest is correspondingly small. Even so, the harvest can be of significant importance to local residents and local economies; fisheries in these islands are still million-dollar industries. But nearshore marine resources are particularly vulnerable to overexploitation and island fisheries are easily overcapitalized.

2. Access to sophisticated exploitation technologies -- Because they are territories of the United States, Puerto Rico and the U.S. Virgin Islands have relatively easy access to state-of-the-art marine harvest technology. There are few

obstacles to entry of fishermen from the U.S. mainland who are typically well-versed in the application of such technology, while capital for fishing operations is more readily available than in other Caribbean islands. These circumstances favor development of fishing fleets whose harvest capacity greatly exceeds the productive capacity of nearshore marine ecosystems.

3. Unplanned and unrestricted growth in the fishery harvest sector -- Olsen and Wood (1983) characterize development in the U.S. Virgin Islands as "rampant and unplanned", and cite as one consequence a tripling of the population since 1960. The growth of the fishing fleets in Puerto Rico and the U.S. Virgin Islands coupled with a relatively small resource base has had a predictably negative impact upon target stocks. Planned development of these fleets is difficult, however, without reliable indications of natural capacity to support harvest.

D. Forecast of Effects of Continued Exploitation Trends

The growth of fishing fleets in Puerto Rico and the U.S. Virgin Islands has been closely linked with development of local tourist industries. Considering the prominent role of tourism in current development plans for Puerto Rico and the U.S. Virgin Islands, it seems likely that without a more directed approach to innovation and growth pressure on nearshore marine resources is likely to increase. Current fisheries development policy emphasizes underutilized offshore resources (e.g., swordfish;

Caribbean Fishery Management Council, 1985) and recreational fishing (M. Pizzini, personal communication, January 1986). This approach has considerable merit, and might help divert fishing effort from stocks which are currently overexploited. But swordfishing is a highly specialized occupation, and the most intensive participation is from vessels based in the mainland United States. At the same time, positive benefits from increased recreational fishing may be diminished by increased numbers of fishermen (encouraged in part by training courses described elsewhere in this report). In any case, all capture fisheries are based upon resources which are ultimately finite, and no development strategy can result in an open-ended stream of benefits. Typically, and unfortunately, there is greater pressure to "develop" than to obtain information on actual development potential.

Csirke (1984) describes six phases which typically characterize the history of an exploited fishery:

1. predevelopment
2. growth
3. full exploitation
4. over-exploitation
5. collapse
6. (sometimes) recovery

While information is not adequate to permit definitive evaluation, spiny lobster and shallow water reeffish fisheries, and possibly conch and deepwater demersal fisheries in Puerto Rico and the U.S. Virgin Islands appear to be in phase 3 or 4. The implications to development are clear: Substantial improvements are unlikely if the "traditional" course of fisheries development in Puerto Rico and the U.S. Virgin Islands is continued.

Besides overexploitation, nearshore marine resources are jeopardized by the destruction of critical habitats discussed above. In 1979, the leading specific problem identified by both commercial and recreational fishermen was water contamination (Clapp and Mayne, 1979). Dredging and shoreline modification associated with tourist developments are a major threat to nearshore resources, both in Puerto Rico and the U.S. Virgin Islands. Juhl and Dammann (1976) noted that coral reefs in Puerto Rico are being "seriously threatened by human activity," including dredging, land erosion, oil, industrial and thermal pollution, and direct harvest (for curios). While a pragmatic justification for these activities might be based on the relative dollar returns from tourism vs. fishing, it should be remembered that many of the features which attract tourists are inextricably linked with the quality of nearshore ecosystems (coral reefs, sport fishing, fresh seafood, clean beaches, etc.).

Obviously, these trends are not unique to Puerto Rico or the U.S. Virgin Islands. But because of their relatively small size, these islands have less capacity than most territories to absorb the consequences of mismanagement. There are few or no adjacent areas to which fishermen or tourists can move when nearshore environments are seriously damaged. The strong dependence upon one productive sector (tourism) make local economies highly vulnerable to any circumstance which adversely affects this sector. The same consideration of limited "buffer" capacity applies to nearshore marine ecosystems. Coral reefs, in particular, grow extremely slowly, and are dependent upon complex interactions between species. Alteration of these systems can produce changes which are essentially irreversible.

E. Impact of Potential Exploitation Technologies

Given the susceptibility of nearshore marine resources to overexploitation, technologies which would materially increase the harvest capacity or efficiency of local fishing fleets should be expected to have a negative long-range impact. If currently harvested resources are being fished at or beyond maximum sustainable yield (as seems to be the case), effort within the fishing fleet must either be reduced or diverted to other stocks. The latter course is clearly the more desirable, and there probably are stocks which are presently underexploited. One possibility is to increase the nearshore harvest of pelagic fishes including migratory tuna and dolphin, possibly in conjunction with fish aggregating devices (discussed below). It is important to note, however, that it is probable that the same stocks are also fished by foreign vessels in distant waters beyond U. S. jurisdiction. In addition, these stocks are the target of fisheries development plans in most Eastern Caribbean countries. Recent work by Oxenford and Hunte (1984), for example, indicates that Barbados, St. Vincent, St. Lucia, and possibly Grenada are exploiting the same stock of dolphin (*Coryphaena hippuris*) whose northern limit is the U.S. Virgin Islands, suggesting that collaboration may be necessary with other countries in the Lesser Antilles to achieve effective management and optimum use of these resources. Most of the world's tuna stocks are already exploited close to maximum sustainable yield (A. Dammann, personal communication, June, 1985). Other nearshore stocks which may be underexploited include squid and deepwater crabs (Olsen *et al*., 1978), and shark.

But the point in all cases is that while an increase in the harvest of underutilized species is possible, there is no reason to suppose that these stocks are less liable to overexploitation than others, and development of alternative fisheries should be based on reliable estimates of sustainable yield. While some innovations may be necessary to achieve optimum harvest of stocks which are currently underutilized, the limited extent of all nearshore marine resources requires that the impact of technological changes be carefully evaluated before widespread implementation throughout the fishing fleet.

In recent years, there has been increasing interest in technological innovations which may increase landings of desirable species by providing artificial shelters. In some cases, the artificial structures serve to aggregate target species, and natural production levels are not altered. In others, it seems possible that natural production has actually been enhanced which should allow harvests greater than would be possible without artificial enhancement. Prototype artificial reef projects in Montserrat, British Virgin Islands, and the U.S. Virgin Islands suggest that increased production of shallow-water fishes is possible using scrap automobiles and tires. Another approach involves the use of structures designed specifically to increase production of selected species. A recent study in Florida indicates that fish biomass on Japanese "designed reefs" was two to six times greater than on scrap metal "reefs" (Schmeid, 1985).

A variety of mid-water fish aggregating devices (FADs) is being used experimentally in the Lesser Antilles (R. Walters, personal communication, March 1983; G. McIntosh, personal communication, July, 1985). Studies by the U.S. Virgin Islands Division of Fish and Wildlife have shown that catch rates are significantly increased by deployment of FADs. Units installed close to the edge of the coastal shelf are reported to attract many migratory pelagic species, particularly dolphin; an estimated 30 - 40 large dolphin may be caught each day around a single FAD (J. LaPlace and R. Gomez, personal communication, July, 1985). The impact of this technology on fish stocks and sustainability of these catch rates has not been evaluated.

In summary, there is a variety of potential exploitation technologies which could improve fish landings as well as management of currently overexploited species (by diverting fishing effort to other stocks). But because of the limited nature of nearshore marine resources, the long-term impact of most innovations is likely to be negative unless their implementation is consistent with the productive capacity of the stocks be harvested.

F. Requirements and Impacts of Resource Management Technologies

Considering current patterns of use and development described above, three major activities appear necessary to achieve sustained development of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands:

1. Management plans must be developed for major nearshore ecosystems. Because fisheries of Puerto Rico and the U.S. Virgin Islands are characterized by a diversity of species rather than commercially important quantities of single species, efforts to manage these resources also should be focussed on groups of

species or systems. A recent report by the World Resources Institute suggests that preservation and enhancement of the living marine resource harvest requires development and application of an ecosystem conservation principle whereby all associated species, the relevant habitat, and spawning and nursery areas are jointly managed.

Fishery management plans being developed by the Caribbean Fishery Management Council (CFMC) provide an excellent starting point for sustained development of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands. Their primary shortcomings have been that they are intended to focus on single species or groups of species rather than entire systems, and must address currently exploited species before consideration can be given to underexploited resources. Recently, the CFMC has initiated development of a Generic Fisheries Management Plan for the geological shelves of Puerto Rico and St. Croix (A. E. Dammann, personal communication, June, 1985). This approach appears more compatible with the multispecies character and complex ecological relationships of nearshore fisheries. If this approach is developed further, the CFMC could oversee the acquisition and synthesis of information to provide for

a. preparation of a strategy for controlled development of nearshore marine ecosystems

b. management and development plans for specific underutilized resources

c. continued monitoring of the condition of ecosystems and utilized stocks

The CFMC is not expected to undertake such tasks unilaterally; rather, involvement of academic, government, and private voluntary agencies is envisioned with overall coordination by the Council.

2. Steps must be taken to limit harvest effort applied to nearshore marine stocks. Development efforts which have been directed toward increasing the number of fishing units without regard for sustainable yield appear to have resulted in overfishing of shallow-water reeffish stocks, and probably conch and spiny lobster as well. Cato and Prochaska (1981) describe an important characteristic which makes many fisheries vulnerable to overexploitation:

> In general, expansion of an industry entails greater demands on raw materials or inputs. This in turn increases the value of the inputs and hence the cost of the product, while the increased availability of the product tends to lower final product prices. Growth is controlled by the limitations on profits imposed by rising cost of inputs and falling product prices. But many fisheries are based upon common property renewable natural resources, and no price is paid for inputs. As a result, growth and fishing effort can increase beyond the level needed for maximum economic yield, until the increased harvest costs due to overfishing curtail production. Because fishery resources are free to those who harvest them, there is no incentive to reduce

fishing effort; on the contrary, rising prices due to demand exceeding supply provide a powerful incentive to increase effort. Panayotou (1982) points out that for this reason, maximum economic yield cannot be attained in an open-access fishery.

The concept of limiting the number of participants in a fishery ("limited entry"; Rettig and Ginter, 1980) is a formallized process in some industrialized nations as well as in various small-scale traditional fisheries (e.g., Klee, 1978; Spoehr, 1980; Johannes, 1978). In the latter cases, limited entry has evolved as an integral part of community function, rather than as part of a formal system of policy and management. Bermuda has recently instituted a system to limited participation in local fisheries to those fishermen who operate on a full-time basis.

Limited entry systems are only partially effective in regulating effort, because fishermen typically increase their effort (and sometimes harvest efficiencv) when such systems are imposed. Still, it is clear that unregulated expansion of local fishing fleets is contrary to optimum sustained use of nearshore fisheries in Puerto Rico and the U.S. Virgin Islands. Action which would prohibit a portion of current fishermen from further participation in local fisheries is probably not politically realistic. However, less opposition would be anticipated to freezing participation at current levels. In the case of resources which are not heavily utilized at present, more rigorous constraints could (and should) be applied to limit the number of fishing units to a level expected to be less than that corresponding to maximum sustainable yield. Such restricitions could obviously be modified from time to time as better information became available on resource abundance; in fact, trial commercial fishing may be the best means for obtaining sustainable yield estimates in small island fisheries (Munro, 1983).

3. Initiatives by local organizations to improve management of nearshore marine resources must be encouraged. Of particular relevance are the activities of the Virgin Islands Resource Management Cooperative (VIRMAC; cf. Rogers and Zullo, 1985). This group consists of 14 federal and territorial government agencies, as well as private research and educational institutions from the U.S. Virgin Islands, British Virgin Islands, and Puerto Rico. VIRMAC is involved with developing management strategies for the Virgin Islands Biosphere Reserve. A variety of potential benefits to nearshore fisheries are associated with this activity including improved information on major stocks and ecosystem processes, establishment of breeding reserves for heavily exploited or threatened species, and provision of information needed for rational development of underutilized species. Because of the commonality of marine resources, these benefits may also be significant to other Lesser Antillean countries, and prospects for a multi-site regional Biosphere Reserve are being investigated.

The University of Puerto Rico is involved in a variety of activities relevant to development and management of nearshore marine fisheries. The Sea Grant Program at UPR, Mayaguez has recently extended its Marine Advisory Service to the U.S. Virgin Islands in cooperation with the College of the Virgin Islands (St. Thomas) and West Indies Laboratory of Fairleigh Dickinson University (St. Croix). This service provides an important means of linking research and policy agencies with resource users (fishermen, tour operators, etc.). Current activities of the Marine Advisory Service emphasize marine recreation and coastal tourism, particularly development of charter boating as an adjunct to small-scale fishing. This represents an important means of diverting fishing effort from overexploited traditional resources. In addition, an information system is being developed in Puerto Rico to improve real-time reporting of sea and weather conditions by having fishermen provide current meteorological reports directly to the local weather service. Other activities include a ciguatera advisory program, experiments with improved materials for fish traps, workshops on shark longlining, and (in the Virgin Islands) a summer camp on marine ecology (M. Pizzini, personal communication, December, 1985).

The University of Puerto Rico has recently been involved with an assessment of deepwater fishery resources around Puerto Rico and the U. S. Virgin Islands. A related project is also underway to map the aquatic resources of the Caribbean Exclusive Economic Zone using remote sensing techniques (Caribbean Fishery

Management Council, 1985). Investigations of this sort are indicative of UPR's potential involvement with nearshore marine resource management issues.

It is clear that continuation of current trends in development and exploitation of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands will result in

- negative impacts upon the natural resources due to overexploitation and habitat destruction
- negative economic impacts as fishery landings decline in response to excessive harvest pressure
- negative social impacts due to reduced income to fishermen and other businesses dependent upon diminished resources

Because the proposed activities will reduce or avoid these impacts, the net result of proposed action is expected to be positive. Because fishery management plans are targeted toward optimum economic yield, the impact of such plans by definition cannot be negative. The CFMC, for example, has calculated that implementation of proposed management measures for yellowtail snapper and Nassau grouper would reduce economic benefits by about $67,000 after one year, but would provide positive benefits thereafter which would total more than $4.5 million after ten years.

Common objections to limited entry measures are reduction in available jobs and possibly reduced supply of seafood due to decreased numbers of fishermen. These objections do not apply to the activities proposed here because

- the number of fishermen would be stabilized, not decreased
- the supply of seafood should be expected to increase due to improved management of overexploited resources and identification of underexploited stocks

Local initiatives for management at the ecosystem level will provide a counterpressure for trends toward degradation of critical habitats. Maintenance of these habitats will have a positive impact not only on fisheries, but also on recreational and tourism sectors.

III. Aquaculture

A. Potential for Aquaculture Development

Puerto Rico has excellent potential for development of viable aquaculture projects involving a variety of species (Glude, 1980; Pagan-Font, 1982) as indicated by the following conditions:

1. Environmental Factors: Puerto Rico receives easterly trade winds throughout the year, and has a generally mild tropical climate. The island is mountainous, and level lands occur primarily in the coastal plain. Major cities, industrial development, and sugar cane fields occupy much of these plains. Areas with elevations less than 700 ft generally have high enough temperatures to support year-around production of certain warm water species. More cold-tolerant species, such as channel catfish (*Ictalurus punctatus*), could be reared at somewhat higher altitudes. However, the lower elevations of the coastal plains

are generally recommended as primary locations for aquaculture farms. The south and southwest coasts of the island are the most protected from storm waves by offshore bars, reefs, and islands. Fresh, brackish and salt waters of reasonable quality and sufficient quantity are available in numerous areas. Soils suitable for pond construction are present in a number of places, including much of the land now used for sugar cane (Glude, 1980).

2. Economic Factors: Coastal lands near urban areas are often unavailable or prohibitively expensive, but large areas of agricultural and rural lands could be used for aquaculture. Some of these lands may be too saline for productive agriculture, but may be suitable for production of marine or salt-tolerant species such as Tilapia. Because of the depressed prices for sugar, property currently used for sugar cane production may become available for aquaculture uses if the profit potentials appear favorable.

In general, Puerto Rico has a well-developed infrastructure. There is excellent air transportation among its major cities and between neighboring islands and the U.S. mainland. There are good surface transportation links between Puerto Rico and the mainland and, because Puerto Rico imports more from the mainland than it exports, favorable haul-back rates are probable for island products. There is a good local highway system, and more than 80% of homes have electricity. Processing, packaging, transportation, construction, and financial industries are well-developed, and there is easy access to equipment and other materials from the

U.S. The government and economy are very stable and U.S.-based. Materials and services, including research, extension, and both skilled and unskilled labor are available. Unemployment is relatively high (20%; M. Pizzini, personal communication, January 1986) and per capita income low ($2126 in 1980; M. Pizzini, personal communication, January 1986) by U.S. standards. The University of Puerto Rico provides students with good training and research experience in aquaculture, but experienced hatchery and farm managers may have to be brought in from other areas. While agriculture in Puerto Rico declined markedly with increased industrialization begun in the 1950's, increased emphasis is being placed on production of local food products. But increased mechanization is often necessary for farms to be profitable, and consequently employment needs are not likely to be met by a renewed agriculture industry (Richards, 1983). Labor intensive aquaculture operations have the potential to reduce this problem.

Substantial domestic markets are available for fishery products, and a burgeoning tourist industry could absorb significant amounts of high value products such as shrimp, prawns, lobsters, oysters, and marine fish. Surplus production would likely find ready acceptance in mainland markets.

Overall, Puerto Rico has good potential and a number of suitable sites for

a. hatcheries for freshwater and especially marine species
b. fresh, brackish, and saltwater ponds with sufficient land to support commercial operations

c. cage, pen, and raft culture in coastal waters

In contrast, the U.S. Virgin Islands appear to have much lower potential for aquaculture development. In terms of climate, the U.S. Virgin Islands are very similar to Puerto Rico. However, the former are much smaller (344 sq km compared to 8897 sq km), with too little suitable land for development of large land-based aquatic farms. There appears to be limited potential for development of saltwater hatcheries and cage/pen culture of fish in coastal waters, but this potential has not yet been adequately researched. Tourism is the main industry, and any aquaculture product would likely find a ready domestic market.

B. Applicability of Various Types of Aquaculture to the U.S. Caribbean

1. Extensive aquaculture is characterized by low stocking density, a relatively low level of environmental control and management, little or no supplemental feeding, and low yields per unit area. Typically, large expanses of low-cost coastal land are required, and they are usually supplied with stockable juveniles captured from the wild (e.g., shrimp farms in Ecuador; milkfish farms in southeast Asia). Small-scale (i.e., "backyard pond") extensive aquaculture is practiced in some areas (e.g., *Tilapia* farming in Africa), more for subsistence than for profit production. Such small farms are likely to require support from a seed production/collection and distribution service.

For most species likely to be of major interest in the Caribbean, Puerto Rico and the U.S. Virgin Islands lack both the land and seed resources to support the development of extensive commercial aquafarms. In Puerto Rico, there is potential for development of small, backyard farms for Tilapia, freshwater prawns, and perhaps other species to provide supplemental income for rural people. However, such development is likely to occur only if the government establishes some sort of seed supply service. One attractive means of doing this, and an alternative to construction of a government hatchery, is for the government to contract with private business for production and distribution of the necessary seed. In this manner, government could encourage the development of both seed supply and grow-out operations in the private sector. Larvae of the mangrove oyster, Crassostrea rhizophorae, are available in coastal waters and might support some form of limited cultivation in protected bays. This oyster, however, is not considered to be a prime product and would require great care with regard to public health considerations.

2. Semi-extensive pond culture is characterized by generally smaller, more engineered and manageable ponds than many of those used for extensive aquaculture, significantly greater control over the pond environment through manipulation of water flow, aeration, fertilization, etc., higher stocking density with heavy or complete reliance on a hatchery for supply of seed, and moderate to heavy reliance on supplemental feeds. Costs and yields per unit area are generally much higher than in extensive

ponds. Examples of semi-intensive pond culture include catfish farming in the U.S., prawn farming in Hawaii and Jamaica, Tilapia farming in Jamaica, and now many of the more successful shrimp farms in South America and elsewhere.

For semi-intensive aquaculture to be successful, suitable sites for both hatchery and grow-out operations must be available. Both Puerto Rico and the U.S. Virgin Islands have excellent sites for hatcheries for a variety of saltwater species (Glude, 1980), and Puerto Rico has adequate land with suitable soils for development of commercial farms for fresh-, brackish-, and salt-water species (Glude, 1980). Some aquafarm development of this type is already underway in Puerto Rico (e.g., Sabana Grande Prawn Farms, Ltd.), and semi-intensive pond culture of various species is likely to be a major area of commercial aquaculture development for the island in the future.

3. Intensive culture characteristically involves a high degree of control over the environment such as can be attained in tanks and raceways, high stocking densities, complete reliance on artificial feeds, and very high productivity per unit area. Intensive culture systems require a high-technology approach and generally involve heavy water use, such as in flow-through raceways, or filtration and water reuse. To date, most intensive aquaculture systems remain in the experimental or pilot phases of development (e.g., Marine Culture Enterprises' highly intensive shrimp farm in Hawaii), with few having attained commercial viability (e.g. raceway culture of trout and catfish in Idaho and

California). Intensive aquaculture systems are not recommended for the U.S. Caribbean because of the lack of a proven, transferable technology for most species, the very high degrees of experience and management necessary to make such systems work, a lack of suitable conditions/sites for proven systems, and the very high level of risk involved. There have already been some notable and costly failures of intensive culture systems for freshwater prawns (Florida and California), lobsters (the Caribbean and elsewhere), shrimp (Chicago), and oysters (Hawaii).

4. Cage and pen culture involve the placement of cages, net-pens, rafts or other culture enclosures in lakes, rivers, estuaries, and coastal bays. This type of production is used primarily for fish, but raft culture of some molluscs (e.g., scallops) is practiced in some areas outside the Caribbean, and pilot scale operations have been undertaken in Jamaica (Wade, 1981). Pen culture of fish generally requires intensive management; very careful site selection to insure protection from damaging waves, currents, and winds, but with sufficient depth and flow to provide adequate flushing; high stocking rates; complete reliance on artificial feeds; and control of diseases, parasites, and fouling. Several species of fish are being successfully cultured commercially in net-pens or cages in various areas of the world. At present, most investigations of cage culture potential for Caribbean finfish appear to have been done in Martinique where preliminary results indicate that yellowtail snapper (Ocyurus chrysurus), permit (Trachinotus falcatus),

palometta (Trachinotus goodei), and European sea bass (Decentrarchus sp.) have commercial potential. Other species under investigation elsewhere and deserving consideration for the U.S. Caribbean include redfish (Sciaenops ocellata), epinephilid groupers, striped bass (Morone saxatilis) and its hybrids, Tilapia, dolphin (Coryphaena sp.), and amberjack (Seriola dumerili). Numerous sites with reasonable characteristics for cage and pen culture of fishes appear to be available in Puerto Rico and to a lesser extent in the U.S. Virgin Islands. Because of heavy reliance of these islands on imported products to meet their demand for fish, evaluation of this means of increasing domestic production should be given a high priority.

The Marine Systems Laboratory of the Smithsonian Institution has demonstrated the potential for producing large quantities of algal biomass in floating cages at Grand Turk Island (Peyton, et al., 1985). Considerable interest has recently developed in using this biomass as a food source for cultured species, particularly the spider crab Mithrax spinosissimus. Available data (Porter, et al., 1985) are too preliminary to establish the feasibility of large-scale culture, though pilot projects are underway in Antigua and the Dominican Republic. Data are not available from market studies which establish the suitability of Mithrax as a substitute for snow crab or Alaskan king crab. Considerably more developmental research is needed before high priority is given to developing spider crab mariculture in the U. S. Caribbean.

5. Sea ranching generally involves the production of juveniles of an aquatic species in a hatchery with subsequent release to the wild to enhance natural populations. Although this procedure has been attempted with a variety of species, including shrimp, it is perhaps best known and most widely practiced for salmon. To be successful, such stocking programs must be accompanied by strong measures to control fishery pressure, possibly with habitat protection and/or enhancement. In the Caribbean most interest in sea ranching has focused on the queen conch because of declining stocks due to heavy fishing pressure throughout the region. Conch hatcheries have been established by the Foundation for PRIDE in the Turks and Caicos, in Bonaire, Venezuela, Mexico, and at the University of Puerto Rico (Mayaguez). To date, the viability of ranching or restocking operations for queen conch has not been demonstrated, though it is technically possible to develop hatchery operations adequate to support a release program (Siddall, 1983). A 1982 review of recent conch mariculture efforts (Berg, 1983) indicated that commercial conch culture was not a viable proposition, and a similar conclusion was reached at the November 1985 meeting of the Gulf and Caribbean Fisheries Institute. Preliminary data indicate a possible positive impact of stocking, but only if the stocked cohort has adequate habitat and is protected from fishing pressure until after it reaches reproductive age (Appeldoorn and Ballantine, 1983; Ballantine and Appeldoorn, 1983; Iversen, 1983). Although not directly aquaculture, habitat enhancement

(discussed above) often yields good results and deserves research attention.

C. History of Aquaculture in Puerto Rico and the U.S. Virgin Islands

Neither Puerto Rico nor the U.S. Virgin Islands has an extensive history of aquaculture development, though both appear to have good potential for aquatic farming. Aquaculture development in Puerto Rico began around 1970 (Pagan-Font, 1982) or 1971 (Glude, 1980) when research activities were initiated with tilapias, catfish (*Ictalurus punctatus*) and freshwater prawns (*Macrobrachium rosenbergii*). Commercial culture of freshwater prawns began in Puerto Rico in 1974 with the establishment of Caribe King Shrimp, Inc., later joined by Aqua Park West, Inc. Both farms failed following extensive flood damage sustained during hurricanes of 1975 and 1979 (Glude, 1980). A third small prawn farm, Shrimp Unlimited, Inc., was established in 1978 near Sabana Grande with eight acres of ponds. Expansion to 20 acres was begun in 1980, but a series of management problems led the company to discontinue operations in 1982. This farm was subsequently reactivated by a new company Sabana Grande Prawn Farms, Ltd., currently in operation with an additional 100 acres of ponds under construction and a hatchery planned. Other investor groups are considering development of prawn farms, and aquaculture research and extension activities at the University of Puerto Rico are expanding (D. Alston, personal communication, January 1986).

In the U.S. Virgin Islands, aquaculture activities have been limited almost entirely to research and development efforts, most of which has been focused on the artificial upwelling project in St. Croix. This project evaluated the potential of using nutrient-rich deep ocean waters pumped to shore to grow algae which in turn were fed to various species of shellfish (Roels and Gerard, 1970). The research effort extended for more than ten years and while the concept proved technically feasible and much useful scientific data were collected, the economics of the system were not promising. The same facilities were briefly used as a shrimp hatchery. There does not appear to be any other significant aquaculture development in the U.S. Virgin Islands.

D. Social and Ecological Impacts of Previous Aquaculture Development

Because of the limited extent of aquaculture development in the U.S. Caribbean, social and ecological impacts have also been limited. Perhaps the most significant social impact is the encouragement of a certain degree of cynicism, particularly in local financial circles, as to whether aquaculture projects can ever develop from research or pilot phases to viable profit-making enterprises. In balance, the failure rate for aquaculture companies has probably not been unusually high when compared to that of other small businesses based on new technologies or in highly competitive fields (e.g., restaurants). Because of the small scale of aqua-farm development, there has been little positive or negative impact on the labor force or on the seafood import situation. However, successful, large-scale development of aquaculture could yield important benefits in both these areas. Finally, the previous failures and lack of successful aquaculture development compared to some other areas with similar climate may have helped to promote the current expansion of aquaculture research and extension efforts in the region.

The primary ecological impacts of past aquaculture activities have been the introduction of exotic species, especially the tilapias and the Malaysian freshwater prawn into the wild in Puerto Rico. The introduced _Tilapia mossambica_ is now considered a pest because its inferior quality as human food has created consumer resistance to the cultured species (_T. nilotica_). There may also be ecological consequences of competition with native species, though such consequences have not been identified. No adverse consequences of prawn introduction have been reported (D. Alston, personal communication, January 1986).

Major implications of the above for future aquaculture development in the U.S. Caribbean are as follows:

1. Proposed commercial aquaculture projects should be evaluated following criteria listed in Appendix 1, and only those with the highest potential for commercial success or social

benefits within a reasonable time period should receive government-backed loans or investment incentives. Public support for research and extension activities should be increased.

2. Where possible, local businesses, universities, etc. should be involved in projects from their inception. Individuals in such institutions know the local environment and business conditions and can help prevent failures caused by attempts to directly transfer culture technology which is not suited to local conditions.

3. Native species should be evaluated for commercial culture potential prior to wholesale introduction of non-indigenous species. When competition makes it necessary to introduce exotic species, safeguards prescribed by the International Council for the Exploration of the Sea (Appendix 4) should be instituted.

E. Criteria for Successful Aquaculture Projects

Aquaculture projects that are likely to be successful should first be based on species that can be grown under ambient environmental conditions. Projects should be carefully planned, with detailed answers to at least the key questions listed in Appendix 1.

F. Requirements and Expected Impacts of Appropriate Aquaculture Technologies

Aquaculture technologies considered by the authors of this report to be appropriate for possible application in Puerto Rico include:

1. pilot-scale evaluation of the extensive type of marine algae (*Gracilaria* sp.) culture which has shown promising results in St. Lucia
2. hatcheries for prawns, shrimp, and various fish species
3. semi-intensive pond culture of prawns, shrimp, *Tilapia*, catfish, and possibly one or more species of marine fishes
4. cage or pen culture of one to several species of marine fish
5. habitat enhancement and protection, perhaps coupled with very site-specific stocking programs, to improve the availability of target species in the wild

Major requirements and anticipated impacts of these types of aquaculture development are summarized in Appendix 2. Positive impacts of such development include increased employment opportunities, reduction of imports, development of export products, support to local aquaculture ventures by providing seed or brood stock, improved use of marginal agricultural land, and potential increases in standing stocks of certain commercial fishery species. The most probable negative impacts are possible removal of a few coastal areas from general public access, and introduction or inadvertent release of non-native species. Negative impacts may result from small or even unsuccessful ventures, while the magnitude of benefits will depend largely upon the eventual scale of successful aquaculture operations.

The potential for aquaculture development in the U.S. Virgin Islands is believed to be much lower than in Puerto Rico, largely due to the very small size of the islands and their rugged terrain. There does appear to be limited potential for development of hatcheries to supply cage culture operations or farms in other locations. The best potential is probably for cage/pen culture of fish, and for habitat enhancement activities.

IV. Relationships Between Capture Fisheries and Aquaculture

Development of both capture fisheries and aquaculture in Puerto Rico and the U.S. Virgin Islands is constrained by the limited area suitable for these activities. There are, however, significant opportunities for improvements in both sectors which depend substantially upon development-oriented research. Optimum use of nearshore marine resources probably requires attention to both aquaculture and capture fisheries. Wild stocks are needed to supply seed or brood stock for many aquaculture operations, and in fact some aquaculture opportunities (sea ranching and habitat enhancement) are essentially manipulations to natural productive processes in the wild. Aquaculture, on the other hand, can provide adjunct or alternative opportunities to fishing enterprises which are presently marginal, and may have the potential to rehabilitate overexploited stocks.

In some cases, aquaculture production has resulted in unfavorable competition for some commercial fisheries (e.g., shrimp). Such impacts seem unlikely in Puerto Rico and the U.S.

Virgin Islands, because demand greatly exceeds potential harvest from natural production. A ready market exists for products of both capture fisheries and aquaculture, and appears sufficiently diverse to accommodate forseeable production from both activities.

Like most of the existing nearshore fishing operations, the majority of current aquaculture enterprises in Puerto Rico are small-scale (D. Alston, personal communication, January 1986). Both enterprises are undertaken primarily as individual or family businesses. Future development of nearshore fisheries is likely to continue to emphasize small operations for reasons discussed above. Aquaculture, on the other hand, may be developed as individual or commercial enterprises depending upon the species being cultured (there are, for example, certain economies of scale which make small prawn farms less desirable than larger ones).

Marketing in both cases is also an individual affair at present, and it is clear that expanded production in either fishing or aquaculture will require modification to existing marketing systems. While physical infrastructure is either already in place or readily accessible, organizational infrastructure for new marketing systems is not. Aquaculture differs from small-scale fishing in that large quantities of product must be sold at periodic intervals, while fisheries involve more frequent sales of much smaller quantities. It is possible that Sabana Grande Prawn Farms will provide centrallized marketing services to smaller prawn farms (D. Alston, personal communication, January 1986). Revision of marketing arrangements for fisheries harvest cannot be undertaken until the future direction of nearshore fisheries development is determined. Cooperatives are effectively non-existent. Efforts have been made from time to time to organize local fishermen in Puerto Rico and the U. S. Virgin Islands, but sustained cooperative activity has not occured.

Aquaculture involves a high degree of commitment to particular species and possibly to particular product forms. Capture fisheries, being based on multispecies resources, are inherently more flexible and hence are somewhat less susceptible to adverse impacts caused by changing markets. Both are vulnerable to competition from imports. The element of risk inherent in both activities poses a common constraint to credit and insurance. The best approach to this problem is to reduce risk by improving the availability and application of appropriate technology through activities recommended below.

Aquaculture ventures, like capture fisheries, may face problems of resource access. The issue is fairly straightforward for land-based aquaculture, where land tenure systems are well-established. On the other hand, it is very difficult to maintain exclusive rights to production from sea ranching and habitat enhancement ventures because these activities use resources which are traditionally considered common property.

Similar conflicts often arise in regard to use of flowing freshwaters or estuaries.

Many of the potentials and constraints to development of capture fisheries and aquaculture in the U.S, Caribbean also apply to most of the other Lesser Antilles. As a result, there are important opportunities for joint marine resource development ventures between the U.S. territories and the Eastern Caribbean countries. It is emphasized that these opportunities do not primarily involve transfer of U.S. mainland technology, but rather are for collaborative development of technologies appropriate to small-island circumstances. This does not involve an exclusively south-flowing stream of benefits; activity in the independent Eastern Caribbean countries can provide benefits to Puerto Rico and the U.S. Virgin Islands, as illustrated by the development of algae and fin fish culture techniques discussed above.

V. Summary

A. Problems and Opportunities

Sustainable development of aquaculture and fisheries in Puerto Rico and the U.S. Virgin Islands are constrained by

1. the limited extent of nearshore marine resources
2. current development trends likely to result in overexploitation

3. inadequate information on which to base management of currently exploited resources or to develop those which are underutilized
4. absence of experience with successful commercial culture of endemic nearshore marine species, and absence of proven technologies for such culture
5. high incidence of ciguatera which causes consumers to reject an unknown but probably significant portion of fish landings

These problems highlight important opportunities to

1. Maintain the current value of nearshore marine resources through effective management, and probably increase benefits through appropriate development of underutilized resources
2. Improve information to manage and develop of these resources
3. Adapt and develop techniques for commercial culture of endemic nearshore marine species
4. Improve the utilization of the current catch by developing a means for rapid detection of ciguatoxic fishes
5. Assist and benefit from efforts in other Caribbean countries to manage common nearshore marine species

B. Relevant Agencies, Policies, Programs and Regulations

For the most part, these opportunities can be addressed through existing local and U.S. federal agency policies and programs. The Caribbean Fishery Management Council is an appropriate vehicle to coordinate development of management plans for nearshore marine systems. The standards established by the

Fishery Conservation and Management Act for fishery management plans are consistent with optimum sustainable development of fisheries, and are appropriate to nearshore marine systems as well as individual species. Sustainable development of fisheries and aquaculture is also consistent with the Coastal Zone Management Program of Puerto Rico and the U.S. Virgin Islands. Regulatory authority currently vested in the Puerto Rico Department of Natural Resources and the U.S. Virgin Islands Department of Conservation and Cultural Affairs appears adequate to support the activities discussed below.

Particularly significant programs through which financial support may be provided for these activities include

- the National Sea Grant College Program (especially for developmental aquaculture research)
- Dingell-Johnson Act (PL 81-681), which derives funds from a 10% excise tax on fishing rods, creels, reels, artificial lures, baits and flies, and provides support to individual states for fisheries management, habitat protection, and improved public access to fishing waters
- Saltonstall-Kennedy Act (15 USC 713c-2-713c-3) provides that up to 30% of gross receipts collected from import duties on fishery products may be made available to assist research and development projects concerned with U.S. fisheries

Local institutions in Puerto Rico and the U.S. Virgin Islands have demonstrated capabilities for undertaking much of the work needed to realize the opportunities described above. The College of the Virgin Islands through its Virgin Islands Ecological Research Station and the Department of Conservation and Cultural Affairs have undertaken a variety of studies of local fisheries potential (e.g., Dammann, 1969; 1970; Brownell and Rainey, 1971; Olsen and LaPlace, 1981; Sylvester _et_ _al_., 1974). Activities of the University of Puerto Rico and the Virgin Islands Marine Resource Management Cooperative were described in section II.F. Collectively, these institutions have the ability to undertake investigations to provide information needed for preparation of development and management plans for nearshore marine systems.

Considering the limited extent of nearshore resources and indications of probable overfishing, credit and incentive programs for purchase of vessels and gear (e.g., the program for Fishery Credit conducted by the Agricultural Credit Corp.) probably are not conducive to sustainable development of fisheries. Such programs are consistent with the latter objective only when the fishing effort being capitalized is directed toward resources which are known to be underexploited. In August 1985, the Right to Employment Administration of Puerto Rico announced a program to train new fishermen between the ages of 19 and 29 (Galarza, 1985). This training will focus upon more or less traditional harvest of nearshore fisheries; a dubious approach considering the overexploited state of traditional fisheries described above. At present, there is no apparent control over how vessels and gear are used, nor is it clear that the number of vessels supported or fishermen trained is related in any way to the capacity of nearshore systems to support harvest.

These concerns apply to the impact of the Caribbean Basin Initiative (CBI) on nearshore fisheries throughout the Lesser Antilles. Stimulated by CBI, a number of projects related to fisheries and aquaculture have been proposed or implemented in the Lesser Antilles. Available information indicates that these projects typically involve direct transfer of technology from temperate locales to small tropical island circumstances. Projects which involve harvest from wild fishery stocks are based upon overly optimistic yield projections, and are not formulated with a view toward sustainability or resource protection. One project proposed for Grenada involved dredging for conch (G. Thompson, personal communication, June 1985) -- an obviously destructive approach to harvesting a species which is considered to be "threatened as an economic resource" (Goodwin, 1983). Aquaculture projects have been presented as virtually assured of success, despite the checkered history of such projects globally, lack of site-specific pilot evaluations, and logistic difficulties characteristic of small islands.

Evidence from Puerto Rico and the U.S. Virgin Islands strongly suggests that harvest technology is not the problem. Rather, the need is to apply appropriate technology at a level suited to the productive capabilities of natural systems. Continuation of a development style directed solely toward capitalization and harvest efficiency without regard for sustainable yields can only result in resource depletion and adverse socioeconomic impacts. Because of the similarity and probable sharing of marine resources among the Lesser Antilles, it is important that an alternative development style be adopted for CBI fisheries projects as well as similar projects in the U.S. territories. There is a similar need for aquaculture projects which are understood to be technology development and site-specific adaptation activities, rather than guaranteed vehicles for fast profits.

C. Objectives

1. Promote formulation and implementation of a rational plan for development, use, and protection of nearshore marine ecosystems in Puerto Rico and the U.S. Virgin Islands.
2. Augment current efforts to develop a field test for identification of ciguatoxic fishes.
3. Stimulate development and application of technology for commercial culture of endemic marine species.
4. Promote international cooperation in managing common fishery species.

D. Recommended Action

1. The Caribbean Fishery Management Council should:

a. identify information needed to prepare development and management plans for nearshore marine ecosystems of Puerto

Rico and the U.S. Virgin Islands, with specific attention to evaluation of underutilized species

b. identify institutions in Puerto Rico and the U.S. Virgin Islands capable of investigations to provide this information

c. identify ~~req~~uired services which cannot be undertaken by local institutions or agencies

d. investigate means for stabilizing and limiting harvest effort in current fisheries of Puerto Rico and the U.S. Virgin Islands and for controlling fishing pressure on underutilized resources as these are developed, and make appropriate recommendations to the Secretary of Commerce

2. Based on the recommendations of the CFMC, local government, academic, and non-profit institutions should prepare proposals to support relevant activities under applicable funding programs, and upon receipt of funds should undertake these activities in coordination with the CFMC. In particular, efforts to increase the number of fishermen (e.g., through training programs) should be based upon a rational assessment of the harvest effort which can be sustained by the target fishery resources.

3. The University of Puerto Rico and Medical University of South Carolina, in collaboration with other agencies and institutions in Puerto Rico and the U.S. Virgin Islands, should expand the current research program directed toward developing a field test for ciguatoxic fishes; consideration should be given

to obtaining potentially toxic material through recreational fishing vessels.

4. Support should be provided through the Sea Grant College Program for development and evaluation of aquaculture techniques applicable to Puerto Rico and the U.S. Virgin Islands, particularly those which can be used to culture marine species endemic to these territories.

5. The U.S. Caribbean territories and other countries of the Lesser Antilles should be encouraged to exchange information on sustainable development of nearshore marine systems and aquaculture. In particular,

a. The U.S. National Park Service should accelerate activity directed toward creation of a regional multi-site Biosphere Reserve

b. The University of Puerto Rico, College of the Virgin Islands, and South Carolina Sea Grant Consortium should pursue development of a marine advisory network for the Eastern Caribbean

c. The Gulf and Caribbean Fisheries Institute should continue and expand its technical sessions concerning sustainable development of small-island fisheries and aquaculture

6. The U.S. Department of Commerce should provide the CFMC with additional staff support needed to carry out the above tasks

7. The U.S. Congress should

a. provide necessary mandates to the Department of Commerce to allow the CFMC to undertake the above tasks

b. insure that sufficient funds are available to accomplish these tasks through such vehicles as Saltonstall-Kennedy and Dingell-Johnson funds, and/or appropriations for the U.S. Sea Grant College Program and Regional Fishery Management Councils

E. Assessment of Consequences

At the minimum, the recommended actions may be expected to stabilize the current harvest at a level which will maintain the value of the current harvest from nearshore marine fisheries. But because of overexploitation in the current harvest, it is reasonable to expect that implementation of realistic management plans will increase the economic value of the nearshore harvest as illustrated by the case of Nassau grouper and yellowtail snapper described above. Moreover, the location and development of underutilized stocks may be expected to further increase economic benefits from the nearshore fishery. Because no measures are proposed which would directly interfere with current fishing activity, negative social impacts upon fishermen are expected to be minimal.

While there is no guarantee of success, progress toward a simple screening test for ciguatoxic fish has been sufficient to warrant continued and accelerated effort. The development of such a test will improve use of current and future harvests by eliminating rejection of entire species of fish, some individuals of which are not toxic.

Aquaculture offers a variety of virtually unexplored opportunities to increase production of seafood for local and export markets. Because lack of appropriate tested technology is a current obstacle to realization of this potential, a dedicated program to provide such technology may be expected to encourage successful investment in culture enterprises. Progress in such technology can also be expected to suggest means by which wild stocks may be improved or rehabilitated (e.g., through habitat enhancement or stocking hatchery-reared juveniles into the wild).

Involving local institutions in a management and development process directed toward whole ecosystems may be expected to broaden appreciation for the interrelated nature of these systems, and their importance to local economies.

Collaboration with other Lesser Antillean countries on these activities will provide access to developments in other areas of potential use to Puerto Rico and the U.S. Virgin Islands. In addition, such collaboration will provide for better access to regional markets and sources of supply, and will help to improve economic, social, and political ties between the United States and the strategically important countries of the Eastern Caribbean.

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Appendix 1

Criteria for Successful Aquaculture Projects

(adapted from Goodwin et al., 1985)

1. Market Conditions
    a. Can the product be sold?
    b. Where?
    c. At what price?
    d. How much is needed?
    e. In what product form?
    f. Are there seasonal variations in demand, supply, price?
    g. Who else is supplying this market?
    h. What frequency of supply is required?
    i. Are there alternate markets?
    j. What are long-term trends and projections for demand, supply, prices?
2. Culture Technology
    a. How well developed is the culture technology?
    b. Who has it?
    c. What types of facilities are necessary?
    d. Can the organism be reared on a reasonably reliable and predictable basis at commercial scale?
    e. What are the culture requirements of all life history stages?
    f. What characteristics should ideal culture sites for this species have?

g. How close to ideal is the chosen project site(s)?

h. How available are seed, brood stock, feed, or other key elements?

i. Are suitable native species available or will exotics have to be introduced?

j. What handling procedures will be used for exotic species?

k. What are typical growth and survival characteristics of the organism in culture?

l. What, if any, pilot or commercial projects have been conducted with the species and with what results?

m. What commercial projects with this species have failed and why?

n. What kinds of consultants and skilled personnel will be necessary and are they available?

3. Environmental Conditions

a. What are the physical (hydrological, meteorological, edaphic) and biological (productivity, availability of seed and brood stock, occurrence of diseases, predators, pollution) features ofthe site and are these suitable for production of the chosen species?

b. Are all the necessary land, labor, transportation, communications, energy supplies, materials, services,and financing potentially available?

c. Do government policies, cultural factors and the local legal framework (incentives, import-export restrictions, permits) favor aquaculture development?

d. Will aquaculture fit in with other uses of the surrounding environment?

4. Economic Outlook

    a. How large should the project be and why?
    b. Will projected revenues from the proposed project exceed estimated costs in a reasonable period of time?
    c. All costs and revenues to be incurred by the project should be estimated and a pro forma financial statement showing estimated expenditures and returns over a period of several years (usually 10) prepared.
    d. Costs, time requirements, and evaluation criteria for any pilot project should be specified.
    e. The type of business structure (e.g., corporation, limited partnership, sole proprietorship, etc.) should be described and the principals names, if possible.

Appendix 2

Requirements, Problems, and Impacts of Appropriate Aquaculture Technologies

A. Extensive Culture of Algae

1. Requirements: shallow, protected coastal waters with firm substrates and relatively high nutrient levels
2. Impacts
    a. Potential Benefits: increased employment opportunities for relatively unskilled workers and development of an export product
    b. Potential Negative Impacts: removal of fairly large areas of a few coastal bays and beaches from general public access and use.

B. Hatcheries for Freshwater Prawns, Marine Shrimp, and Various Species of Marine Fish

1. Requirements: Site requirements for all species are fairly similar, namely ready access to adequate supplies of seawater (and in some cases freshwater) and suitable temperatures. The larvae of shrimp and most of the marine fish species of interest require high salinities (e.g., 30 ppt or higher) for best results, while prawns need much lower salinities (12 - 16 ppt). Only small areas of land (one to few acres) would be required for most species; however, substantially larger areas (tens of

acres) would be needed for fish species requiring ponds for fingerling production (e.g., redfish, striped bass, etc.).

2. Impacts
    a. Potential Benefits: freedom from reliance on off-island seed suppliers, possibility of developing export sales of seed to other islands, and training local personnel in hatchery techniques
    b. Potential Negative Impacts: inadvertent release of exotic species or disease organisms

C. Tilapia and Catfish

Tilapia require warm waters (generally 21 - 23 C or greater) for good growth and spawning. They are usually reared in freshwater, but several species grow well in brackish and salt water. The Tilapias are quite tolerant of low dissolved oxygen levels, and moderately tolerant of high ammonia and turbidity levels. Earthen ponds are the preferred production system, and the fish will spawn directly in the ponds. The major problem is controlling reproduction to prevent over-population of ponds with resulting severe decrease in growth rates. Like Tilapia, catfish require warm fresh waters, but can be cultured at somewhat higher elevations and lower temperatures. Catfish are less tolerant of poor water quality than Tilapia. The major requirement for culture of Tilapia and catfish will be suitable acreages of ponds.

There is good potential for production of Tilapia and catfish in Puerto Rico. The technologies are proven, and can be applied in monoculture and polyculture systems and at large commercial scale or small-pond scale to supplement income. Land and other resources necessary are available. Production from 1,500 to 2,000 acres of ponds would likely exceed total annual fishery landings from wild stocks in Puerto Rico and thus reduce the island's major dependence upon imported fish. In the future, production (at least of catfish) above that needed to meet local demand could likely be marketed in the mainland. Substantial market development work will probably be necessary for Tilapia, especially if any of the production is to be targeted for mainland markets.

D. Freshwater Prawns

Requirements are similar to those for Tilapia and catfish. Warm temperatures are particularly important since the optimum temperature for growth appears to be about 28 C. According to Glude (1980),

> large areas of land, especially in the Lajas Valley, are suitable for prawn farming, and there is a good local market at high prices.

The technology for prawn culture is fairly well-developed, but not quite as well-proven as that for catfish and Tilapia. Currently, there are no hatcheries in Puerto Rico, although one is reportedly under development. A local supply of seed will be essential for large-scale development.

Glude (1980) projected that by 1990 freshwater prawn farming in Puerto Rico might expand to more than 2,000 acres producing four million lb each year with a farm value of some $20 million. This estimate is probably overly optimistic, but there is good potential for expansion to at least several hundred acres by the end of the decade. An important possibility is the use of marginal agricultural land underlain by brackish waters, such as occurs in the Lajas region, for prawn culture. Prawns do very well in low salinity environments (Sandifer and Smith, 1985). A major problem yet to be resolved is the development or identification of export markets of sufficient magnitude to absorb large quantities of product at prices that will yield profits. However, the domestic market, although not quantified, is believed to be sizeable, especially the tourist-oriented segment.

E. Marine Shrimp

1. Requirements: The major requirement is for salt water ponds in areas protected from storm damage and flooding. Sufficient acreage is needed to allow true commercial development (hundreds to eventually thousands of acres). The technology for pond culture is well-developed and hatchery systems are fairly reliable. The greatest technology weakness is in the area of maturation and reproduction of animals in captivity. Available

technology has been sufficient for an appreciable level of commercial development (one large farm in the U.S. relies almost entirely on captive reproduction), but there is a great deal of room for improvement. This is important since a local seed supply will eventually be needed to support farm development, and such a hatchery will have to be based on captive maturation since large stocks of shrimp do not appear to occur in Puerto Rican waters. With care, captive reproduction technology can be transferred to Puerto Rico and successfully adapted to local conditions.

2. Impacts

a. Potential Benefits: decreased reliance on imported products in both commonwealth and mainland markets via production of a high value product that can be sold locally or shipped to the U.S.; annual income of $6 - 10 million from development of 1,000 acres of ponds each producing an average of 2,000 lb of shrimp tails per year

b. Potential Negative Impacts: introduction and inadvertent release of non-native species [in this regard it is significant that the naturally occurring Penaeus schmitti (Perez Farfante, 1969) has recently been found to be a good species for aquaculture (Weidner, 1985), with demonstrated captive reproduction and good growth characteristics (Sandifer et al., personal observations)]

F. Cage Culture of Marine Fish

1. Requirements: Coastal bays and estuaries with adequate flow to maintain water quality but protected from storm damage are needed for cage and pen production. Property protection will have to be developed through government policies. Sources of juveniles, either from hatcheries or from the wild, are also required. Market studies will have to be undertaken with non-traditional species, but demand is likely to be high.

2. Impacts

a. Potential Benefits: substitution of domestic production for imports

b. Potential Negative Impacts: inadvertent release of introduced species; reduced public access to certain coastal waters; possible overharvesting of juvenile fish from the wild for seed

G. Habitat Enhancement

1. Requirements: Relatively shallow-water coastal areas that lack reefs and other vertical relief

2. Impacts

a. Potential Benefits: increased standing stock of fish and perhaps other species such as spiny lobsters

b. Potential Negative Impacts: poorly anchored or located habitat units may wash ashore during storms

Appendix 3

Major Commercial Shallow-Water Species of Puerto Rico and the U.S. Virgin Islands

(Caribbean Fishery Management Council, 1984)

Family	Common Name	Percent	Genus and Species
Serranidae	Groupers	25.1	Epinephelus striatus
			Epinephelus guttatus
			Epinephelus fulvus
			Epinephelus itajara
			Mycteroperca venenosa
Pomadasyidae	Grunts	16.2	Haemulon plumieri
			Haemulon flavolineatum
			Haemulon aurolineatum
			Haemulon sciurus
Scaridae	Parrotfishes	12.0	Scarus coelestinus
			Scarus coerulus
			Sparisoma viridae
Mullidae	Goatfishes	7.7	Pseudopeneus maculatus
			Mulloidichtys martinicus
Holocentridae	Squirrelfishes	6.7	Holocentus ascensionis
			Holocentrus rufus
Lutjanidae	Snappers	4.3	Ocyurus chrysurus
			Lutjanus jocu
			Lutjanus synagris
			Lutjanus analis

			Lutjanus griseus
			Lutjanus apodus
Balistidae	Triggerfishes	32.6	Balistes vetula
			Canthidermis sufflamen
			Xanthichthys ringens
			Melichthys niger
Sparidae	Porgies	1.5	Calamus pennatula
			Calamus bajonado
			Calamus penna
Labridae	Wrasses	2.4	Lachnolaimus maximu
Ostraciidae	Trunkfish	1.0	Lactophyrys spp.
Chaetodontidae	Butterflyfish	---	Chaetodon ocellatus
Pomacanthidae	Angelfishes	---	Pomacanthus arcuatus
Acanthuridae	Surgeonfishes	---	Acanthurus coeruleus
			Acanthurus chirurgus
			Acanthurus bahianus

APPENDIX 4

GUIDELINES FOR IMPLEMENTING THE ICES CODE OF PRACTICE CONCERNING INTRODUCTIONS AND TRANSFERS OF MARINE SPECIES

by

Working Group on Introductions and Transfers
of Marine Organisms

International Council for the
Exploration of the Sea

GUIDELINES FOR IMPLEMENTING THE ICES CODE OF PRACTICE CONCERNING INTRODUCTIONS AND TRANSFERS OF MARINE SPECIES

This document has been prepared and reviewed by the Working Group on Introductions and Transfers of Marine Organisms. It attempts to clarify information relevant to the Revised Code of Practice concerning introduced species as approved by the Council at its 1979 Statutory Meeting.

Included are the following sections:

(1) The Revised Code of Practice as approved by the Council at its 1979 Statutory Meeting;

(2) A list of definitions for the application of the Code;

(3) An augmentation and explanation of each of the sections of the Code, as appropriate.

(1) "REVISED CODE OF PRACTICE TO REDUCE THE RISKS OF ADVERSE EFFECTS ARISING FROM INTRODUCTION OF MARINE SPECIES"

At its Statutory Meeting in 1973 the International Council for the Exploration of the Sea adopted a "Code of Practice to Reduce the Risks of Adverse Effects Arising from Introduction of Non-indigenous Marine Species." At its Statutory Meeting in 1979 the Council adopted a revised code, as follows:

I. Recommended procedure for all species prior to reaching a decision regarding new introductions (this does not apply to introductions or transfers which are part of current commercial practice).

(a) Member countries contemplating any new introduction should be requested to present to the Council at an early stage information on the species, stage in the life cycle, area of origin, proposed place of introduction and objectives, with such information on its habitat, epifauna, associated organisms, etc., as is available. The Council should then consider the possible outcome of the introduction, and offer advice on the acceptability of the choice.

(b) Appropriate authorities of the importing country should examine each "candidate for admission" in its natural environment, to assess the justification for the introduction, its relationship with other members of the ecosystem and the role played by parasites and diseases.

Note: A marine species is defined as any aquatic species that does not spend

(c) The probable effects of an introduction into the new area should be assessed carefully, including examination of the effects of any previous introductions of this or similar species in other areas.

(d) Results of (b) and (c) should be communicated to the Council for evaluation and comment.

II. If the decision is taken to proceed with the introduction, the following action is recommended:

(a) A brood stock should be established in an approved quarantine situation. The first generation progeny of the introduced species can be transplanted to the natural environment if no diseases or parasites become evident, but not the original import. The quarantine period will be used to provide opportunity for observation for disease and parasites. In the case of fish, brood stock should be developed from stocks imported as eggs or juveniles, to allow sufficient time for observation in quarantine.

(b) All effluents from hatcheries or establishments used for quarantine purposes should be sterilized in an approved manner (which should include the killing of all living organisms present in the effluents).

(c) A continuing study should be made of the introduced species in its new environment, and progress reports submitted to the International Council for the Exploration of the Sea.

III. Regulatory agencies of all member countries are encouraged to use the strongest possible measures to prevent unauthorized or unapproved

IV. Recommended procedure for introductions or transfers which are part of current commercial practice.

(a) Periodic inspection (including microscopic examination) by the receiving country of material for prior mass transplantation to confirm freedom from introducible pests and diseases. If inspection reveals any undesirable development, importation must be immediately discontinued. Findings and remedial actions should be reported to the International Council for the Exploration of the Sea.

(b) Inspection and control of each consignment on arrival.

(c) Quarantining or disinfection where appropriate.

(d) Establishment of brood stock certified free of specified pathogens.

It is appreciated that countries will have different attitudes to the selection of the place of inspection and control of the consignment, either in the country of origin or in the country of receipt.

List of Personal Communications

Dallas Alston, PhD; Department of Marine Sciences, University of Puerto Rico; January, 1986

Arthur Dammann, PhD; Caribbean Fishery Management Council, St. Thomas, U.S.V.I.; June, 1985

Manuel Hernandez, PhD; Department of Marine Sciences, University of Puerto Rico; January, 1986

Joseph LaPlace; Virgin Islands Department of Conservation and Cultural Affairs; St. Thomas; July, 1986 (by Daven Joseph, Island Resources Foundation)

Gregory McIntosh; McIntosh Marine, Fort Lauderdale, FL; July, 1985

Manuel Pizzini, PhD; Sea Grant Program, University of Puerto Rico; December, 1985 and January, 1986

Geoffrey Thompson; Renwick and Thompson, Inc.; Grenada; July, 1985

Randolph Walters, Fisheries Officer; Ministry of Agriculture; Tortola, BVI; March, 1983

Background Paper No. 7

DEVELOPMENT AND MANAGEMENT OF NON-FOOD MARINE RESOURCES IN THE U.S.-AFFILIATED CARIBBEAN ISLANDS

(Author's Draft)

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

ABSTRACT

Since prehistoric times, coastal and insular cultures have harvested and exploited tropical marine organisms for a tremendous range of utilitarian, symbolic and ornamental functions. Traditional uses include: food; clothing; fuel; currency; tools; weapons; herbs; medicinals; religious, magical, and funerary symbols; and, construction materials for dwellings, roads and vessels. Contemporary uses include: industrial and agricultural chemicals; food additives; and, pharmaceuticals. Harvesting technologies range from simple dugout canoes to deep-diving, manned submersibles.

In this paper, I analyze various ecological, economic and regulatory aspects of the exploitation and management of coastal marine resources for purposes other than food among the U.S. affiliated islands of Puerto Rico and the Virgin Islands. Emphasis is placed on comparisons of traditional, contemporary and potential technologies, and on the integration of these activities among other islands within the Caribbean basin.

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INTRODUCTION: THE EXPLOITATION OF COASTAL MARINE RESOURCES

HISTORICAL AND GEOGRAPHICAL PERSPECTIVE

Among the early fossilized traces of prehistoric man lies clear evidence of the routine harvesting and exploitation of organisms from the sea (Grigg, 1977). Since antiquity, marine animals and plants have been incorporated into virtually every dimension of human enterprise. Marine organisms, and products derived secondarily from them, have served a tremendous range of utilitarian, ornamental, and symbolic functions including: food; clothing; fuel; currency; tools; weapons; herbs; medicinals; religious, magical, and funerary symbols; industrial and agricultural chemicals; and, construction materials for dwellings, roads and boats (e.g. Lacaze-Duthiers, 1864; Cox, 1957; Buehler et al., 1962; Grigg, 1977; Wells, 1981; Fisheries Management Plan-Final Environmental Impact Statement for Coral and Coral Reefs (FMP), 1982; McInnes, 1984; National Gallery of Art, 1985).

Not surprisingly, the importance of marine objects varies among different cultures in proportion to their proximity to the sea. For example, although conch shells were commonly traded among aboriginal Americans over great distances (National Gallery of Art, 1985), the breadth of economic and social roles played by marine organisms remains greatest among the 50-70% of the world's population living along coastlines (Salvat, 1981). Most coastal people live in the tropics, and largely among the thousands of islands dotting tropical seas (Salvat, 1981). Thus, a significant fraction of the world's population exploits, and depends upon, organisms harvested from tropical, insular waters.

Caribbean islands have a number of characteristics that facilitate, and occasionally necessitate, the harvesting and exploitation of shallow-water marine organisms. First, geographic constraints commonly limit outside trade and encourage a dependence upon local products. Second, tropical oceanic environments are relatively benign and predictable, and allow near-constant harvesting using locally manufactured technologies. Third, tropical coastal ecosystems are very diverse and support abundant populations of easily accessible organisms. The gross primary productivity of tropical seas -- a basic measure of their capacity to support biological communities -- is said to far exceed that of many temperate waters (Tursch, 1976), and, in some cases, may be double that of a comparable midwestern grain field (Fenical, 1983; Adey, personal communication, 3/85).

RESOURCES AND TECHNOLOGIES

Virtually every major marine plant and animal groups is harvested to some degree by insular peoples in the Caribbean (Table 1). Harvested resources include vertebrates (fishes, turtles, mammals), invertebrates (molluscs, crustaceans, corals, sponges, etc.), plants (algae, mangrove) and inanimate objects (sand, limestone). These resources are used for a variety of traditional and modern non-food functions (summarized in Table 1) including ornamentation, construction materials, medicinals, herbs, and, more recently, pharmaceuticals and industrial chemicals (Grigg, 1977; Wells, 1981; Salvat, 1981; Fenical, 1983; McInnes, 1984). While the range of organisms harvested varies among island groups, one general pattern of resource use emerges: the exploitation of marine organisms has long been, and continues to be, an integral element of Caribbean insular economies and cultures.

Although Caribbean waters have supported continuous subsistence-level exploitation since prehistoric times without discernable negative ecological impacts (Grigg, 1977), recent increases in harvesting intensity wrought by economic, population, and technological pressures threaten to cause serious and irrevocable degradation of these critically important ecosystems. For example, the advent and general availablility of fiberglass boats, outboard motors, snorkeling gear, SCUBA apparatus, and (to a lesser extent) deep-diving submersibles have significantly increased harvesting within previously exploited habitats. Moreover, and perhaps ultimately more important, the new markets and demands generated by such advanced technologies encourage the exploitation of entirely new habitats and organisms formerly inaccessible to relatively primitive traditional harvesting methods. Compare for example, the minimal depth and taxonomic range accessible from a traditional Caribbean dugout canoe (Figure 1) to that of the deep-diving manned submersible used to harvest precious corals in Hawaii (e.g. Grigg, 1976, 1977). Technological advancements in peripheral fields such as industrial chemistry increasingly generate demands for new sources of natural compounds (Fenical, 1983). Similarly, new diseases and increased resistences to existing drugs stimulate an intense search for pharmaceuticals derived from compounds synthesized naturally by harvested marine organisms. Combined, these essentially economic processes -- technology transfer and increased market demand -- have accelerated harvesting pressures, and pose new and potentially serious ecological consequences for tropical coastal ecosystems.

RESOURCE MANAGEMENT

Historically, coastal resources have shown a consistent pattern of human use: exploration, discovery, exploitation and, finally, depletion (Grigg, 1977; McInnes, 1984). Although simplistic attempts at marine resource management were made as long ago as the middle ages (Grigg, 1977), serious concern for the consequences of uncontrolled and unplanned exploitation is a relatively recent development. Progress in tropical coastal management is limited, however, by five factors: i) the relative lack of generally applicable ecological data; ii) the complexity and unpredictability of tropical marine ecosystems; iii) jurisdictional ambiguities created by incomplete and non-specific laws and regulatory statutes (Grigg, 1976, 1977; FMP, 1982; SPO, 1983); iv) low levels of enforcement; and, v) insufficient recognition of the regional nature of these ecological issues and lack of scientific cooperation among Caribbean states. Due to these limitations, many current or potential levels of exploitation already exceed our capacity to either analyze, regulate, or enforce resource management programs.

PAPER SUMMARY

In this paper, I analyze various ecological, economic and regulatory aspects of the exploitation and management of coastal marine resources for purposes other than food among the U.S. affiliated islands of Puerto Rico and the Virgin Islands (St. Croix, St. John, St. Thomas). Many taxonomic groups are harvested for a variety of unrelated uses, and harvesting technologies span equally broad range of non-overlapping methods (Table 1). Below, after reviewing the pertinent ecological characteristics of tropical coastal habitats, I examine in detail three categories of resource use and associated harvesting/management technologies: i) artifacts (jewelry, curios, displays); ii) pharmaceuticals (derived from marine organisms); and, iii) miscellaneous uses (construction materials, fuel). Within each category, relevant data are reviewed for vertebrates, invertebrates, plants and inanimate resources. Two basic questions are addressed throughout. 1) What are the historical and contemporary patterns of resource exploitation and mangagement? 2) What are the potential opportunities and constraints for future development and management of coastal resources in the Caribbean.

CARIBBEAN COASTAL ECOSYSTEMS: AN ECOLOGICAL OVERVIEW

ECOSYSTEM CHARACTERISTICS, FUNCTIONS AND EXPLOITATION

The complexity and variability of Caribbean coastal environments are exceeded only, perhaps, by tropical rain forests. Taxonomic composition and overall community structure vary widely within and among islands, even over short distances (Glynn, 1973). Nevertheless, meaningful ecological generalizations can be made by grouping similar habitats into a few functional categories whose members share certain fundamental biological characteristics. For example, although the islands in the U.S. Caribbean differ widely in size, topography and oceanographic conditions, all share one common feature. Their coastal ecosystems comprise three distinct, but intimately interdependent habitats: mangrove forests, seagrass meadows, and coral reefs (Glynn, 1973; Rogers, 1982; SPO, 1983). Below, these habitats are summarized with particular emphasis on ecological characteristics related to their exploitation and/or management.

I. Mangrove Forests

"Eminently characteristic of a tropical shore is the dense belt of Mangrove bushes with which it is in many places lined. To an (sic) European it is a strange sight to see a grove of trees growing actually out of the sea, and his admiration is not diminished when he examines more closely the structure of these singular plants. The trunk of every tree springs form the union of a number of slender arches (roots) ... which penetrate into the mud. There seems to be a continual encroachment of the land upon the sea in certain parts of the coast by the agency of this tree." P.H. Gosse, 1851. A Naturalist's Sojourn in Jamaica.

Walls of mangroves straddling land and sea are one of the most conspicuous features of Caribbean islands, and are ubiquitous throughout the

U.S. affiliated islands (Figure 2). Three species of mangrove occur in varying abundances throughout the Caribbean: red, black and white mangroves. Although obviously dominated by mangrove trees, these forests actually comprise a very complex and diverse association of animals and plants (both marine and terrestrial) whose members range from tiny filamentous algae to areal bromeliads, and from microscopic zooplankton to frigate birds, turtles and alligators. Fringing mangrove forests -- dominated by red mangrove and forming dense, narrow walls at the shore -- are common throughout the U.S. affilated islands, particularly on the south shores of large islands. On the smaller islands and islets (e.g. off the south shore of Puerto Rico), dense, mixed-species forests may cover entire land masses.

Mangrove trees are uniquely adapted for colonization of new sandy shores. Their long, torpedo-shaped seeds germinate while still attached to the parent plant, and easily penetrate the underlying shifting sediments when released. Leaves develop underwater and grow upward toward the surface (Figure 3). This highly localized mode of sexual reproduction creates a gradually advancing front of new trees continually added to the existing forest.

Mangrove forests are an integral component of Caribbean coastal ecosystems and fulfil many fundamentally important functions in the ecology and economy of the region (SPO, 1983). First, as forests develop and spread, the increasingly dense network of "prop" roots (Figure 4) traps and stabilizes sediments, eventually forming new land where it had not previously existed above the water line. Second, fringing mangrove forests protect existing coastlines and structures from erosion during seasonal storms and hurricanes (Tannehil, 1952; Neumann et al., 1978; Armstrong, 1981; Woodley et al., 1981). Third, the subtidal portions of the prop roots serve as a semi-permanent hard substrate which supports an extremely diverse and ecologically important community of marine plants and invertebrates. This assemblage is generally dominated by bivalves (Figure 5), algae, sponges, anemones (Figure 6), ascidians (Figure 7) and small crustaceans. Fourth, the sheltered waters among the roots function as a nursery for schools of commercially important fin-fish including jacks, grunts, grouper, snapper, and barracuda (Figure 8). Fifth, mangrove branches often support rookeries for many species of sea bird including frigate birds, brown boobies, and the endangered brown pelican (SPO, 1983). And finally, mangrove forests generate significant amounts of nutrients (both particulate and dissolved) which are carried out to sea and augment the growth of adjacent seagrass and coral reef communities.

Mangroves are harvested in the U.S. affiliated islands and throughout the Caribbean for fuel and for building materials used in fish traps (C. Rogers, personal communication, 9/85), dwellings and other structures (SPO, 1983). In addition, mangroves are often removed secondarily to gain access to sites used for sand mining, navigation channels, waste dumping, or the construction of dwellings and docks (SPO, 1983). Organisms associated with mangrove forests, particularly fishes, turtles and bivalves, are commonly harvested for food and artifacts.

II. Seagrass Meadows

Between the shore and the reef crest (Figure 9) there often exists a broad expanse of shallow, protected waters containing a dense meadow of the seagrass, _Thallasia testudinum_, and other species of vascular plants (Armstrong, 1981; SPO, 1983). Although such meadows often appear to be simple homogenous tracts of seagrass amid patches of sand and coral rubble (Figure 10), they in fact support a diverse community which plays important roles in the ecology and economy of coastal regions. The seagrass habitat comprises four separate but interactive assemblages: i) the grass itself (a vegetatively spreading angiosperm); ii) small invertebrates and algae growing epiphytically upon the grass blades; iii) burrowing animals (Figure 11) moving among the unconsolidated sediments (e.g. shrimps, worms, sea urchins, and sea cucumbers); and, iv) the mobile (crawling and swimming), epifaunal animals moving freely on or above the surface (e.g. fishes, turtles, conch (Figure 12) lobsters, crab, squid, octopus, manatee, etc.).

Like mangrove forests, seagrass meadows serve many crucial ecological functions of both direct and indirect economic importance to Caribbean insular peoples. Seagrasses consolidate the otherwise unstable sandy sediments, protecting shorelines and coastal structures from storm erosion. Moreover, the same mechanism eventually creates thick accumulations of sand upon which mangroves advance, further consolidating the land. Seagrasses provide shelter for many commercially important food animals including lobster, conch, squid, octopus and a variety of fin-fishes, many of which migrate to and from seagrasses either daily or at a fixed stage during their life cycle. For example, although many food fishes live (and are harvested) on the open coral reef as adults, they pass the critical larval and juvenile phases in the relative protection of seagrass meadows.

Although seagrass itself is of little intrinsic economic value, the associated sand, coral rubble, fishes and invertebrates are harvested commonly for materials and food throughout the U.S. affiliated islands and elsewhere in the Caribbean region.

III. Coral Reefs

Perhaps the most striking coastal features of the U.S. affiliated Caribbean islands are the massive coral formations fringing or dotting their shores (Figure 13). Broadly defined, a "coral reef" comprises both the physical structure formed by the gradual growth of coral animals plus all of its associated biota. Virtually every major animal and plant group is represented, and in many cases exploited, on coral reefs in the U.S. affilated Caribbean (Table I). These include sponges, algae, octocorals, hydrocorals, crustaceans, fishes, turtles and others (Figure 14).

The ecological and economic importance of coral reefs is a direct consequence of way in which corals grow. Corals are morphologically simple animals resembling the common temperate sea anemone, but differing from them in two fundamentally important characteristics. First, corals are colonial animals, and therefore grow not by simple linear extension of the individual (as we do), but rather by asexual budding or cloning of thousands of copies of the original individual that had settled on the sea floor as a free-swimming larva. These genetically identical budded individuals, or polyps (Figure 15), remain physically and physiologically attached, and continue to bud indefinitely with no apparent upper limit to either colony size or colony age (Hughes and Jackson, 1980). Thus, large coral colonies may contain tens of thousands of cloned individuals and be hundreds or perhaps thousands of year old. Second, corals secrete a massive, intricate, rock-like skeleton beneath the thin layer of living tissue containing the polyps. It is this permanent carbonate skeleton that forms the massive reefal structures protecting Caribbean coastlines, and creating inumerable habitats for the associated biota.

Three reef formations occur in the Caribbean: i) barrier reefs (long stretches of reef offshore); ii) fringing reefs (relatively narrow bands closely paralleling the shore); and, iii) patch reefs (small "islands" of coral in the midst of either sand or seagrass meadows). Both fringing and patch reefs are common among the U.S. affiliated islands.

Coral reefs vary widely in shape, size and species composition, even over short distances. This variation, which can severely confound attempts at comprehensive resource management, stems from two sources. First, the overall profile of any reef is largely a reflection of the topography of the underlying island rock, much of which was itself formed by ancient fossil reefs and subsequently eroded by periodic changes in sea-level over the last ten thousand years. Second, superimposed upon this large-scale topography, the structure of any given reef also reflects its local history of growth alternating with destruction by various natural and (increasingly) human-induced disturbances. The former includes hurricanes, extreme low tides, earthquakes, etc. (see Woodley et al., 1981, for review). This degree of variability and unpredictability in reef community development must be incorporated into comprehensive management plans for coastal Caribbean resources.

Corals and coral reefs serve at least three functions of profound economic importance. First, the mere physical structure serves as a barrier to storm waves and the debris they carry, without which, most low-lying coastal areas would be periodically decimated by severe storms (e.g. Woodley et al., 1981). Second, coral growth creates complex habitats for a variety of economically important organisms including molluscs (conch, squid, octopus), crustaceans (lobsters, crab, shrimp), fishes (grouper, snapper, grunt, etc.), and a number of colonial invertebrates (chiefly corals and sponges) taken as artifacts for the souvenir trade (Table 1). Third, many reef-dwelling animals are preyed upon by migrating and pelagic fishes which constitute a major portion of commercial fisheries in the region.

Corals and their associated flora and fauna are routinely harvested for many purposes throughout the Caribbean. These include artifacts, building materials, pharmaceuticals, and other chemicals (Table I).

COASTAL ECOSYSTEMS: DISTURBANCE, RECOVERY AND MANIPULATION

A fundamental ecological characteristic of any natural community is its susceptibility to major disturbance or purturbation. "Susceptibility" incorporates both the frequency and severity of disturbance, and the community's capacity to recover to previous levels of abundance and diversity. Although tropical coastal systems such as mangroves, seagrasses and coral reefs generally escape the wild environmental and population fluctuations characteristic of many temperate coastal environments, they do, nonetheless, experience a range of severe physical and biological disturbances of both natural and human origin (Woodley et al., 1981). Below I briefly describe their causes, effects and implications for the management of non-food marine resources among the U.S. affiliated Caribbean islands.

I. Sources and Characteristics of Disturbance

Natural disturbances in the Caribbean result from both physical and biological processes. Physical disturbance agents include: hurricanes (Figures 16-19); earthquakes; extreme low tides; extreme water temperatures (e.g. El Nino); fresh-water runoff; and, terrigenous sedimentation. Biological disturbance agents include predator outbreaks (e.g. crown of throns starfish); pathogen epidemics (e.g. black band disease in corals); naturally introduced competitors; and, unusual drastic population pulses of ecologically important species (e.g. the recent Caribbean-wide die-off of urchins and the resultant destructive bloom of their algal prey).

Sources of human-induced disturbance include: increased sediment runoff from agriculture and construction (e.g. Kaneohoe Bay, Hawaii); thermal and chemical effluents from industry; oil spills; ship damage (grounding and anchors); dredging and blasting during channel construction; direct removal of exploited species; and indiscriminately destructive fishing methods (chlorine, dynamite, grenades, etc.).

Although most major disturbances -- natural and human -- are, by definition, relatively rare and unpredictable, they occur with sufficient frequency and severity that virutally any program of resource exploitation and management in shallow, coastal waters would eventually experience their effects.

II. Recovery Processes

The immediate impact of disturbance on coastal communities, and on their subsequent recovery and development, is influenced by three characteristics: i) its selectivity (differential effects among co-occurring organisms); ii) its capacity to cause structural changes in the habitat (i.e. the wholesale destruction of corals in hurricanes); and, iii) its duration (i.e. rare and short vs. chronic and prolonged). Table 2 compares these features among the major natural and human disturbance agents in the Caribbean. Recovery is likely to be slowest and most unpredictable following non-selective, destructive and chronic disturbance. Although the patterns are complex, it is clear that both natural and human disturbances vary widely in community-level effects, and cannot be treated equally in analyses of resources management schemes.

Moreover, disturbances do not necessarily act independently; their effects can interact synergistically to magnify the total impact. For example, corals stressed by a major hurricane in Jamaica showed increased susceptibility to a subsequent and independent epidemic of disease (J. Lang, personal communication, 8/84). Similar interactions have been hypothesized in relation to human-induced pollution stress.

The ecological and evolutionary consequences of disturbance are a major focus of contemporary, tropical, marine research (e.g. Woodley et al., 1981). And although recovery processes are clearly fundamental to this question, very little is known and even less is agreed upon. Current information stems from two sources: i) long-term observations of naturally disturbed communities;

and, ii) theoretical models based on extrapolations from smaller-scale routine processes such as larval recruitment patterns, etc. If a concensus exists about recovery processes, it is that while one may be able to predict the approximate sequence in which major taxa will appear in the community, one cannot predict their specific composition or ultimate community structure. This minor theoretical annoyance represents a profound impediment to management plans dealing with either natural or human (planned) disturbance. For example, recovery patterns depend upon two processes: i) the survival and growth of surviving organisms; and ii) the recruitment of new organisms into the community by migration or reproduction. Given that many of these larvae and migrating adults may travel great distacances and originate in potentially unmanaged habitats controlled by different political criteria, local recovery patterns are virtually impossible to predict or control.

III. Ecosystem Manipulation

The intentional manipulaton of ecological communities is merely a participatory form of disturbance, and as such, is subject to the same uncertainties. No large-scale community manipulations comparable to those in temperate habitats have been described for the Caribbean. The complexity of Caribbean coastal ecosystems, and our relative ignorance of the most basic ecological characteristics of their components, virtually preclude successful community manipulations at any but the highest (and economically irrelevant) taxonomic levels. Before communities or even single populations of benthic organisms can be predictably manipulated toward some desired end, more basic research on life history characteristics and ecological interactions must be done.

TECHNOLOGY ASSESSMENT

Exploitation and management patterns are described below for three major uses of Caribbean coastal resource: i) artifacts; ii) drugs; and, iii) miscellaneous. Within each category, significant historical, comtemporary and potential trends are examined (wherever relevant) for vertebrates, invertebrates, plants, and inamimate objects.

ARTIFACTS

I. Sessile and Sedentary Animals: Corals and Molluscs

Background. The trade in mollusc shells and precious corals is among the oldest forms of maritime commerce, having been in continuous existence for over 7 thousand years (Lacaze-Duthiers, 1864; Cox, 1957; Grigg, 1976, 1977; Wells, 1981; FMP, 1982; McInnes, 1984). Corals were used by Celts during the Iron Age to adorn weapons (Wells, 1981), and are found abundantly in Arawak and Carib indian middens throughout the Caribbean (FMP, 1982). Similarly, shells have been used since prehistoric times as ornaments, currency, horns, mystical and funerary objects, horns, drinking vessels, and construction materials (Cox, 1957; Wells, 1982; FMP, 1982). Conch middens are so extensive in some places in the Caribbean that entire islets have been constructed, *de novo*, by shells discarded over centuries (McInnes, 1984). Five coral groups are, or have the potential to be, harvested in the Caribbean: stoney corals (scleractinians; Figures 20-21); horny corals or sea fans (gorgonians; Figures 22-23); hydrocorals (Figure 24); gold corals (zoanthids), and black corals (antipatharians). Molluscs harvested for shells include: conchs (Figure 12), helmets, volutes, cones, nautilus, tritons (Figure 25), spiny oysters (Figure

26), and scallops (McInnes, 1984). A few Caribbean molluscs, particularly the conchs, are exploited for multiple uses (e.g. food and artifacts).

Sources and Markets. Historically, the Mediterranean was the center of the precious coral trade (Lacaze-Duthiers, 1864). However, with the decline in coral populations caused by overfishing in the early 1800's, activity shifted toward the Pacific where 95% of all traded corals now originate (Grigg, 1976, 1977). Similar patterns apply to molluscs. Major contemporary exporting countries of corals and molluscs include the Philipines, Taiwan, Japan, Hawaii, and in the Caribbean, Mexico, Haiti and Honduras (Grigg, 1976, 1977; Wells, 1981; FMP, 1982). Major importers include the U.S., Japan and Europe. Coral imports to the U.S. have increased steadily since 1970, and exceeded 2000 tons in 1976 (Wells, 1981). American imports of molluscs exceeded 4600 tons in 1976 (Wells, 1981). During the 1970's, Haiti alone exported over 60 thousand conch shells, many of which were sold through the over 1000 shell dealers in the U.S.

Currently, the harvesting of corals and other sessile or sedentary animals is restricted in the U.S. affilated Caribbean islands by various Federal and Commonwealth statutes. Exceptions are made for small-scale collections for scientific, educational or personal use (SPO, 1982; FMP, 1982; C. Rogers, personal communication, 9/85; A. Berger-Blundon, personal communication, 9/85). Despite this level of protection, the poaching of corals for the tourist and aquarium trade is ubiquitous throughout the Caribbean region, and is unlikely to diminish. Molluscs are not protected, with the exception of conchs and other species living within the federal waters and parks (SPO, 1983).

Technologies. Traditional methods of coral harvesting involved sail powered boats dragging hooks or dredges along the bottom (Grigg, 1976, 1977). Molluscs continue to be harvested from shallow Caribbean waters while wading or swimming, or from small dugout canoes (Figure 1). The advent of snorkeling and SCUBA diving equipment during the last few decades greatly increased the efficiency and depth range of harvesting. More recently, the depth and time constraints associated with SCUBA diving have been circumvented by the use of remote-controlled and manned deep-diving submersibles, as in the precious coral fishery off Maui, Hawaii (Grigg, 1976, 1977).

Such new technologies have a number of mixed ecological and social impacts. For example, shallow-water technologies such as SCUBA compete directly with traditional harvesting methods and can quickly lead to a general overfishing of communual resources (J. Woodley, personal communication, 7/81). In contrast, Modern deep-water technolgies such as manned submersibles generally do not overlap in harvested species with tradtional methods, and actually permit greater harvesting selectivity and avoidance of the indiscriminate destruction of undesirable specimens (Grigg, 1976, 1977). They do, however, vastly increase the number of habitats and taxa susceptible to intense exploitation, and may eventually displace the more common and less exotic traditionally harvested products.

Resource Management. The history of coral and mollusc fisheries is one of progressive exploitation leading to chronic depletions (Grigg, 1976, 1977; Salvat, 1981; Wells, 1981; McInnes, 1984). Conchs and black corals are heavily overfished throughout the Caribbean, including populations among the U.S. affiliated islands (SPO, 1983; McInnes, 1984; personal observation). Primitive management efforts date basck as far as the Middle Ages when coral fisherman rotated harvesting beds to allow recovery (Grigg, 1976, 1977). Nevertheless, rigorous scientific efforts to manage these resources are a relatively recent phenomenon. Black coral fisheries are currently under study and/or management in the U.S. Virgin Islands, Puerto Rico, British Virgin

Islands, Netherland Antilles, Bahamas, Bonaire, and Jamaica (Mailer and Woodley, 1981; Newton and van't Hof, 1981; Wells, 1981; SPO, 1983; C. Rogers, personal communication, 9/85).

Optimum sustainable yield models (OSY) have recently been applied to to the exploitation and management of the deep-water Hawaiian precious coral fishery (Grigg, 1976, 1977). All such efforts, however, are limited ultimately by the necessity to rely upon grossly estimated values for critical -- but largely unstudied -- ecological parameters such as longevity, reproductive capacity, larval and population dynamics, and environmental stability. Progress in the comprehensive management of corals and other sedentary or sessile animals will depend ultimately upon the acquisition of such basic biological information, perhaps by using the same advanced technology currently used in their exploitation.

Resource Development Potential. The development of a rational and sustainable management scheme for exploitation of benthic colonial animals (including very deep taxa) requires further basic ecological research. Specific issues are described later.

Ultimately, however, future levels of exploitation may be influenced less by scientific merit than by three essentially economic and technological processes. First, as tourism increases in the Caribbean (SPO, 1983), levels of personal and commercial collecting of corals and shells are likely to follow. Second, two major coral and shell exporters, Haiti and the Philipines, have enacted strict export restrictions in response to environmentalist's concerns (Wells, 1981; FMP, 1982). Consequently, demand is up and the rewards for increased exploitation are rising, with both Mexico and Honduras increasing export levels accordingly. Third, new advanced harvesting technologies, such as submersibles, provide access to entirely new habitats and organisms whose "rarity" and novelty create instant and lucrative demand for intense exploitation (Grigg, 1976, 1977). One consequence of such technological advancements, however, is the jurisdictional and regulatory ambiguity relating to the depth of regulated territorial vs. international waters off tropical islands (Grigg, 1976, 1977).

II. Mobile Animals: Turtles and Fishes

Four species of sea turtle occur commonly in the Caribbean: hawksbill, green, leatherback, and loggerhead. All are variously protected from harvesting or molestation by living within federal waters or by their status as endangered or threatened species (SPO, 1983). Moreover, strict import controls apply to the mere possession of turtle products inthe U.S. Nevertheless, turtles have long been hunted intensely in the Caribbean and continue to be poached and sold, even among the U.S. islands, for food and fine jewelry (SPO, 1983; FMP, 1982). Turtles are easily caught in nets, by hand, or on the beach while laying eggs. The general availability of outboard boats and synthetic netting aggravates the problem, and the economic value of turtles ensures that low-level poaching will likely continue. Beyond increased enforcement at the local levels, only accelerated pulic education and basic research on population dynamics and migration can alleviate the harvesting pressures on these threatened species.

Many tropical fishes are harvested for sale in the aquarium and curio trade. Fish are taken using small boats, nets, traps, and/or narcotizing chemicals such as quinaldine or (to a lesser extent, chlorine). An example of the nature of this activity is seen among the easily captured pufferfish, which are killed, inflated, varnished and mounted on mobiles and lampshades for sale in curio shops locally or on the mainland U.S. S. Except for populations within federal parks in the U.S. Caribbean, fishes are generally not protected from exploitation for such trivial purposes.

PHARMACEUTICALS AND OTHER CHEMICALS

Background. Many pharmaceuticals now in use were originally isolated from terrestrial plants and microbes. Recently, marine plants and animals have also proven to synthesize a tremendous range of biomedically and industrially important compounds (Thomson, 1976; Fenical, 1983; Pike, 1984). These are found abundantly among benthic (attached) algae (Figure 27), coelenterates (especially the gorgonians), sponges (Figure 28), and a number of other invertebrate taxa (Faulkner, 1976; Mirale, 1976; Scheuer, 1978; Fenical, 1983; Pike, 1984). Major functional groups of natural marine chemicals include sterols, carotenoids, diterpenoids, prostoglandins, and hydrocarbons (Faulkner, 1976; Minale, 1976; Fenical, 1983). While their natural functions remain poorly understood (W. Fenical, personal communication, 6/85), their potential uses in medicine and industry are broad and important (Table 2) (Pike, 1974; Faulkner, 1976; Mirale, 1976; Tursch et al., 1978; Fenical, 1983).

Current research on marine natural products has four major areas of focus: i) isolation and characterization of novel compounds; ii) determination of their biosynthetic origin and natural function(s); iii) assays of their biological activities and potential uses; and, iv) methods of commercial production using laboratory synthesis via genetic engineering or other (biomimetic) techniques (W. Fenical, personal communication, 6/85). The majority of researchers are based in universities and industry throughout Europe, Japan and the U.S.

Technologies. Contemporary marine biochemical technologies bear little resemblance to traditional methods of extracting medicinal substances from shallow-water organisms, which mainly consisted of boiling algae picked while wading along the shore. Benthic organisms are now harvested on a relatively large scale using snorkeling, SCUBA, and remote or manned submersibles (S. Pomponi, personal communication, 6/85). Bioassays and preliminary chemical extractions are performed immediately, often onboard a large, ocean-going research vessel. Organisms showing interesting activity patterns are further collected for subsequent laboratory analyses requiring more sophisticated isolation and identification techniques. Finally, compounds possessing significant economic potential are used as models for laboratory synthesis on a large, commercial scale (D. Faulkner, personal communication, 7/77).

Management. Management of marine natural products resources and activities has attracted relatively little concern for three reasons. First, the field is relatively young and has yet to pose a recognizable environmental impact. Second, harvesting impacts are obscured by short times spent in any location, and by the fairly limited areas sampled. Finally, and most importantly, laboratory synthesis of useful compounds has generally proved more cost effective than continued large-scale harvesting far from the home laboratory. Combined, these factors mean that localized ecological impacts are perceived to be negligable and temporary.

A past exception to this general pattern, however, illustrates a potentially important future management issue. In the early 1970's, Upjohn conducted extensive field research on the large-scale harvesting and aquaculture of a Caribbean gorgonian that contained very high concentrations of a medically useful prostoglandin. Although laboratory synthesis was then possible, its cost far exceeded that of harvesting the abundant field populations (Pike, 1984). The research eventually concluded that repeated partial pruning of colonies in a large, marked population might supply sufficient quantities of tissue for immediate needs, while permitting the regrowth of partially harvested colonies (Hinman, 1974; Kinzie, 1975;

Schroeder, 1974). Interestingly, although improved synthesis eventually displaced large-scale field harvesting, it was the cost/benefit ratio of harvesting vs. synthesis, and not simply the absolute ability to do one or the other, that determined the source of the compounds, and the local environmental of its production. Economic analyses do not remain constant, but rather vary through time and among countries with changing conditions. Thus, Cuba and Mexico, Caribbean countries whose economies differ vastly from ours, continue to harvest this species as a source of medical prostoglandins. Future economic conditions or biomedical demands could easily dictate such large-scale harvesting of benthic organisms in the waters of the U.S. affilated Caribbean islands. Thus, it is important to develop guidelines and techniques now for the management of these resources based on sound basic ecological research (see discussion below).

Despite economic and medical potential associated with the exploitation of marine natural products, it is, for several reasons, relatively unlikely tc directly affect or involve local populations. First, sampling (harvesting) times are short, and not necessarily restricted to delimited or regulated areas. Second, virtually all aspects of the process, from harvesting to synthesis and production, are conducted by experts in chemistry or taxonomy, usually based elsewhere. One potential source of profit and control in marine pharmaceutical development may lie in formal agreements to share in any profits gernerated directly from organisms harvested locally. Analagous issues are currently under great debate in the field of genetic engineering.

MISCELLANEOUS USES

A variety of biological and inanimate resources are harvested from Caribbean coastal waters for uses as either construction materials (sand and limestone) or fuel from biomass conversion (algae).

I. Biomass Conversion

In several places in the Caribbean, including St. Croix, pilot programs have studied the feasibility of converting raw algal biomass into methane gas and other sources of cheap, non-polluting energy (Fenical, 1983; R. Carpenter, personal communication, 8/85). Algae are grown on enclosed (often floating) artificial substrates, harvested periodically, and converted chemically to gas. Two major problems influence the success of this process: i) the relative scarcity of large, fleshy algae (Figure 27) in the Caribbean, particularly in light of intense fish grazing; and, ii) the cost of nutrients and processing chemicals.

Biomass conversion is a very recent development and has no traditional counterpart in Caribbean cultures. It does, however, have the potential to employ significant numbers of people in fairly unskilled, non-technical work with few negative ecological consequences.

II. Construction Materials: Sand and Limestone

Two natural, if somewhat indirect, products of coral growth are sand and limestone. Most of the unconsolidated sediments along Caribbean shores are generated by erosion directly from corals and other organisms which secrete a mineralized skeleton. Similarly, the limestone platforms and cliffs ringing many Caribbean islands (Figure 29) represent the fossilized remains of ancient coral reefs left exposed by changes in sea-level.

Both sand and limestone are quarried for use in the construction of roads, buildings and beaches throughout the region, including the U.S. affiliated islands (SPO, 1983; C. Rogers, personal communication, 9/85). Current levels of exploitation are low. However, the future development of new sand mining areas, such as the large deposit of the western Puerto Rico and Vieques (SPO, 1983) could pose potentially serious ecological risks.

Sedimentation is a well-documented cause of large-scale destruction of coral reef communities, with the resultant decline in the associated economically important organisms such as fish and crustaceans (Galzin, 1981). The large-scale removal of sand or limestone blocks from below water line may simply involve more environmental dangers than it is worth economically.

RESEARCH, EXTENSION AND EDUCATION

Before plans are made to develop Caribbean coastal resources, two quesions must be addressed. First, does the potential economic and social value of continued or accelerated exploitation outweigh the associated long- and short-term ecological risks? And, second, do we possess the minimum basic ecological data to make the necessary informed judgements? While the first answer is undoubtedly debatable, the second is clearly "no". Below, I describe areas of research and related education fundamental to these issues.

RESEARCH

Although there has been intense interest in subtidal tropical marine communities for centuries, it has only been in the last three decades -- since the advent of SCUBA gear -- that rigorous field research was possible. As a consequence, less is known about these ecosystems than about any other of comparable extent and importance. Future management decisions must be made based on solid basic ecological and biological data. Below, I list 5 general areas of research relevant to such decisions.

1) **Life history characteristics of important organisms**: age at first reproduction; age/size dependent mortality and fecundity schedules; growth rates; longevity; and, patterns of energy allocation among ecologically important physiological processes.

2) **Larval ecology**: modes of larval development, release, nutrition, migration and settlement; maximum dispersal distances; extent and mechanisms of habitat selection; relation between egg numbers (fecundity) and larval numbers (fertility) numbers in gravid females; interactions between larvae and settled adults of same and different species.

3) **Ecological interactions among species**: frequency and consequences of

competition, predation, parasitism, and muturalism; role of guilds and functional groups in community dynamics; indirect interactions.

4) Role of disturbance in community structure and development: frequency, predictability and consequences (short- and long-term) of disturbance; sources of disturbance (natural vs. human); synergistic interactions between independent disturbance events; methods of recognizing "signatures" of past disturbances in recent and fossil communities; evidence of evolutionary adapatation to major disturbance sources.

5) Exploiting cloned colonial invertebrates (corals, etc.): limits to regeneration of lost tissues and skeleton; minimum fragment size required for growth, reproduction and survival; genetic and environmental stability of low diversity cloned populations; use of artificial substrates for animal culture.

EDUCATION AND EXTENSION

The ultimate value of such information, however, will depend largely on the degree to which the affected public, leglislators and enforcement personell appreciate the major ecological issues involved in exploitation of coastal resources. Given the financial constraints on local enforcement (SPO, 1982), it is likely that public awareness and cooperation will prove as important as regulation in preventing overexploitation. Many forums for education and extension exist. These include: the schools; national parks (USVI-NP); mass media; and national marine sanctuaries (proposed).

SUMMARY: PROBLEMS AND OPPORTUNITIES

Compared to the Pacific and elsewhere in the Caribbean, levels of harvesting and exploitation of non-food resources are relatively low among the U.S. affiliated islands. Two factors contribute to this situation. First, fairly stable economic conditions obviate the need for subsistence-scale harvesting of organisms for sale as artifacts. Second, many of the relevant habitats fall within a number of Federally protected parks and recreation areas (e.g. Buck Island and Virgin Islands National Park), and are thereby prevented from overexploitation (C. Rogers, personal communication, 8/85).

Nevertheless, the future of these habitats is by no means assured. Poaching and small-scale personal collecting continue, and may ultimately pose a serious threat to the sustainability of populations. Furthermore, changes in the relative costs and benefits of protecting coastal resources may eventually dictate their accelerated development and exploitation. For example, a pressing medical need for a marine-derived drug could quite easily justify the large-scale harvesting of the relevant species in U.S. waters.

Effective management of coastal resources is, and will likely continue to be, severely limited by the general lack of relevant basic ecological data. Two solutions to this critical problem exist.

First: basic research on important ecological processes in tropical marine habitats should be among the high priorities of Federal funding agencies. These include: the National Science Foundation; the National Institutes of Health; the National Cancer Institute; the National Oceanic and Atmospheric Administration; the Environmental Protection Agency; the Sea Grant Program; and, the Agency for International Development. International or private funding agencies include: the United Nations; the World Wildlife Fund;

and the Rockefeller Foundation.

Second, and equally important: cooperative research and management efforts must be further encouraged among all Caribbean basin states. Many ecologically and economically important processes (e.g. larval recruitment) operate over great distances, and often affect many islands (and governments) within the region simultaneously. Consequently, it is necessary to both recognize the regional nature of these issues, and to implement cooperative management programs for issues of general interest. Such Caribbean-wide cooperation would produce at least two major benefits. First, the coordination of data gathering and analysis would maximize research efficiency and avoid costly overlaps in a field not overly endowed with rearch funds. Second, using this information, regional cooperative management plans could be implemented and generally enforced. The Virgin Islands Management Cooperative, involving 14 agencies, is such an effort. Similar joint projects should be encouraged throughout the Caribbean Basin.

SOURCES OF PERSONAL COMMUNICATION

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TABLE 1.

Exploitation patterns of Caribbean coastal resources showing, for various resource categories: i) the relevant technologies and uses; and, ii) their habitats of origin. (+)= harvested. (-)= not currently exploited. Arti= artifacts. Drug= pharmaceuticals and other chemical natural products. Misc= other uses such as construction, fuel, etc. Mang= mangrove forests. Seag= seagrass meadows. Reef= coral reef.

RESOURCE CATEGORY	USE/ TECHNOLOGY				HABITAT		
	ARTI	DRUG	MISC	FOOD	MANG	SEAG	REEF
I. VERTEBRATES	+	+	-	+	+	+	+
A. Turtles	+	-	-	+	+	+	+
B. Fishes	+	+	-	-	+	+	+
C. Mammals	-	-	-	+	+	+	+
II. INVERTEBRATES	+	+	+	+	+	+	+
A. Molluscs	+	-	+	+	+	+	+
1) gastropods	+	-	+	+	+	+	+
2) bivalves	+	-	+	+	+	+	+
3) cephalopods	+	-	-	+	-	+	+
B. Coelenterates	+	+	+	-	+	+	+
1) corals	+	+	+	-	+	+	+
2) black coral	+	+	-	-	-	-	+
3) gorgonians	+	+	-	-	+	+	+
4) hydrozoans	+	+	-	-	+	+	+
5) anemones	+	-	-	-	+	+	+
C. Crustaceans	+	-	-	+	+	+	+
1) crabs	+	-	-	+	+	+	+
2) lobsters	-	-	-	+	+	+	+
3) shrimp	-	-	-	+	+	+	+
D. Sponges	+	+	+	-	+	+	+
E. Ascidians	-	+	-	-	+	+	+
F. Echinoderms	+	+	-	+	+	+	+
1) sea urchins	+	-	-	+	+	+	+
2) sea cucumbers	-	+	-	+	+	+	+
3) star fish	+	-	-	-	+	+	+
III. PLANTS	-	+	+	+	+	+	+
A. Mangroves	-	-	-	-	+	-	-
B. Algae	-	+	+	+	+	+	+
IV. INANIMATE	-	-	+	-	+	+	+
A. Sand	-	-	+	-	+	+	+
B. Limestone	-	-	+	-	+	+	+

TABLE 2.

Major sources and potential characteristics of natural and human disturbance in Caribbean coastal habitats.

SOURCE	SELECTIVE	DESTRUCTIVE	CHRONIC
NATURAL			
Physical			
hurricane	+	+	-
earthquake	+	+	-
sedimentation	+	-	-
fresh water	-	-	-
tides	+	-	-
temperature	-	-	-
Biological			
predator outbreaks	+	-	+
disease epidemics	+	-	+
competitor intros.	+	-	+
population crash	+	-	+
HUMAN-INDUCED			
sedimentation	+	-	+
thermal effluents	-	-	+
chemical effluents	?	-	+
ship groundings	-	+	-
ship anchors	-	+	-
channel dredging	-	+	-
species exploit.	+	+	+
destructive fishing	-	+	+
oil spills	?	-	-

TABLE 3.

Biomedical, industrial and agricultural uses of natural compounds isolated from marine plants and animals.

BIOMEDICAL

- anti-tumor (cancer)
- anti-viral
- anti-bacterial
- anti-ciliate
- anti-helminth (worm)
- smooth-muscle control
- circulatory system
  - blood pressure
  - blood flow
- female reproductive physiology regulation
  - induced menstruation
  - induced labor
  - therapeutic abortion
- birth control

INDUSTRIAL AND AGRICULTURAL

- food additives
  - sweetners
  - thickeners
  - preservatives
- solvents
- antifreeze
- dynamite
- animal feed
- potash
- iodine
- bromide
- insecticide
- herbicide
- hydrocarbons (diesel fuel)
- plastics

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Background Paper No. 8

APPLICABILITY OF ZEOLITE REFRIGERATION SYSTEMS TO SMALL TROPICAL ISLANDS

by

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1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

ABSTRACT

Zeolites provide a unique solution to the adsorption cooling problem with low grade heat because of their nonlinear sorption properties. They are therefore capable of adsorbing large quantities of refrigerant gases at low temperatures and pressures, thus providing refrigeration and cooling. When heated in a closed system, zeolites desorb the refrigerant gases at pressures sufficiently high to permit condensation at ambient temperature.

For small tropical islands, solar coolers using natural zeolites as the adsorbent are currently under commercial development and can provide immediate on-site refrigeration for perishable produce and animal products. The coolers can be of considerable importance for the refrigeration of fish in remote fishing villages on tropical islands where refrigerated transportation is not immediately available. The zeolite cooling-heating system can improve productivity of livestock breeding, feed utilization, dairy and egg production by moderating the ambient temperature of the livestock shelters, without interference with the roof water catchment systems in existence.

The zeolite solar freezer, which needs further development before it can be marketed, can be of great importance for ice production on islands or remote locations without available electricity as well as providing long-term storage of frozen food and processed products. The indirectly-heated zeolite system currently being developed independently, seems perfectly suited for resolving the refrigeration problems in mobile applications, such as refrigerated trucks and small boats since this system is considerably lighter, cheaper and can use the waste heat generated by the internal combustion engine which is usually associated with mobile propulsion.

The major drawback to the zeolite solar technology is that it is, like any solar system, heavily capital intensive and therefore the people who need it most can least afford it without large initial subsidies by governmental or charitable organizations. Where such technology is used to increase the income of the island's population by providing marketability of perishable products which was previously unavailable, low-interest loans could possibly be repaid by the additional new income in reasonable time periods. The indirectly-heated zeolite system has low initial cost and can be used without any subsidies whenever free waste heat is available.

The zeolite systems have no adverse social or cultural effects and their beneficial impact on small tropical islands can be significant if the economic conditions are properly managed.

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INTRODUCTION

Conventional sorption-refrigeration cycles utilize the variation with temperature of the solubility of a gas in a liquid, either ammonia in water, or water vapor in lithium bromide (ASHRAE 1977). Such cycles are used extensively for commercial air conditioning and refrigeration whenever an inexpensive supply of heat (usually steam) is available. They can achieve an overall efficiency (also called coefficient of performance) of 70 to 80% if the source of heat is about 100°-200°C and the condenser is water-cooled to below 25°C (R.T. Ellington 1957). Solar collectors, however, generally provide hot water at temperatures of less than 90°C. Furthermore, an air-cooled condenser is necessary for residential applications, and such a condenser can reach 50°C on days when the air temperature is 40°C. Under such conditions, the efficiency of conventional sorption systems drops drastically and many systems simply stop operating altogether.

Zeolites provide a unique solution to the above problems of solar cooling because of their unusual sorption properties. They are capable of adsorbing large quantities of a variety of refrigerant gases, ranging from water vapor and ammonia to carbon oxides and freons (D.W. Breck 1974). Interestingly enough, for most of these gases the amount sorbed is about the same -- 30 weight percent (D.I. Tchernev 1977). Because the heat of vaporization of water is the largest of any common refrigerant and about 10 times larger than that of the freons, the zeolite-water vapor combination can provide the most efficient system and requires the smallest quantity of adsorbent for its operation. Zeolites also have the unique property, which is of critical importance for solar applications, that their adsorption isotherms have an extremely nonlinear pressure dependence. In contrast with zeolites, other sorbents have almost linear pressure isotherms (D.I. Tchernev 1978).

Of the many synthetic and natural zeolites tested for solar cooling application, chabazite from Bowie, Arizona and clinoptilolite from Sheaville, Oregon proved to be most efficient. A more detailed discussion of the properties and selection of the best natural zeolites for solar cooling application can be found in a previous paper (D.I. Tchernev 1980).

The major potential benefits of the zeolite solar-powered cooling and refrigeration units will be in locations where energy costs are high and electric power is unavailable, unreliable, or expensive. This situation commonly occurs in small tropical islands such as U.S.-affiliated islands of the Pacific and Caribbean areas. In such locations, a major application will be for the storage, preservation or transportation of perishable food products, such as tropical fruits, fish and shellfish, vegetables, meat or milk and milk products. The refrigerated storage of vaccines and serums in local hospitals and dispensaries is a further benefit since cold storage is required by the World Health Organization for the immunization program in order to increase the shelf life of the vaccines used.

Where tourism is an important industry, the zeolite space-conditioning system could provide living comfort at reasonable cost and the same would be true for office buildings and other commercial structures.

Finally, the ice-making capabilities of the zeolite refrigeration system could be used for small scale manufacturing of ice on islands where full scale commercial ice-making facilites are not justifiable.

TECHNOLOGY ASSESSMENT

Operating Principle

Figure 1 illustrates the principle of operation of a zeolite solar-cooling system. The zeolite is sealed in an airtight container that is irradiated by the sun. During the day cycle, shown on the left side of Figure 1, the zeolite and its container are heated to a maximum temperature of 120°C. At about 40°C, water vapor starts desorbing from the zeolite, and its partial pressure in the closed system begins to rise. When the pressure reaches the value determined by the condenser temperature, for example 55 mm Hg for 40°C, the vapor begins to liquefy, heat is rejected to the outside, and liquid water flows to a storage tank. During the night cycle, on the right side of Figure 1, the zeolite is cooled by convection cooling to ambient temperature and is ready to adsorb water vapor even at low partial pressures. Liquid water from the storage tank is introduced into the evaporator, where it adsorbs heat from the space to be cooled and is converted into water vapor. If the partial pressure can be maintained at 5 mm Hg, the water in the evaporator will boil at 2°C. The zeolite then absorbs the water vapor produced by the evaporator, maintaining the partial pressure below 5 mm Hg and rejecting the heat of adsorption to the atmosphere. At the end of the night cycle the zeolite is loaded with all the water it will adsorb at 5 mm Hg and is ready for the beginning of a new day cycle.

A zeolite system, like any refrigeration system, has to be free of air. Therefore, the zeolite is placed in hermetically-sealed metal panels. These panels, which are painted black for maximum solar adsorption, are connected through ordinary plumbing to the condenser, water-storage tank, and evaporator. After the zeolite is charged with water vapor, the whole system is outgassed, evacuated, and sealed.

Zeolite Solar Refrigerator

Zeolites can provide refrigeration and manufacture ice using the sun's energy without any other external power requirements and without any moving parts. A view of a solar refrigerator presently manufactured by The Zeopower Company is shown in Figure 2. It consists of a solar zeolite panel on top, an air-cooled condenser in the center, and a storage-tank-evaporator on the bottom, inside a commercial icebox. A solar refrigerator having an efficiency of 15% produces about 900 watt-hours of cooling for each square meter of collector area receiving a solar input of 6 kWh. This amount of cooling corresponds to about 9 kg of ice manufactured per day for each square meter of collector.

The zeolite solar panel resembles a conventional flat-plate collector. For the extreme condensation and evaporation pressures of 55 and 4 mm Hg, respectively, the differential water loading of most zeolites is about 7% by weight between ambient temperature and 120°C, which is about the maximum temperature attainable with present flat-plate solar collectors. In practice, the loading is closer to 5% by weight. The panels have a zeolite capacity of about 50 kg/m^2 and require a depth of 5 cm. The upper surface of each panel is painted black, and pipes are provided at the bottom to permit the water vapor to enter and leave. Each panel is leak-tested prior to use.

Zeolite Heating/Cooling System

A complete system that would utilize solar energy for agricultural heating and cooling is shown schematically in Figure 3. The condenser and evaporator are combined into a single unit that is cooled by an external water loop. During the day, water vapor desorbed from the solar heated zeolite is condensed in this unit, and the heat of condensation is rejected to the external water loop. This heat can provide hot water and space heating during the winter season. During the winter season, hot water is stored during the day to provide heat during the night, as in any conventional solar system. Whenever there is a demand for heat, hot water from the storage tank is circulated through a coil located in the air ducts of the forced air system, and the heated air is distributed throughout the building. If too much heat is liberated in the condenser, as for example in the spring and summer, the excess can be rejected to the outside by an air-cooled coil. During the night, water in the condenser-evaporator unit evaporates from the same surfaces on which it originally condensed, and the vapor is adsorbed on the cool zeolite. The external water loop provides the necessary heat of vaporization, producing chilled water for use in air conditioning and space cooling. The chilled water can be stored during the summer season in the same storage tank used for hot water during the heating season. The changeover from one season to the other is achieved by simple valving. During the heating season, when chilled water is not desired, liquid water from the condenser-evaporator is fed directly into the zeolite panel, bypassing the evaporation process. In contrast, conventional heat pumps always require the use of an evaporator, whose operation necessitates an external source of heat, even during the winter.

A pair of collectors was installed at a 30^0 angle facing south in Tucson, Arizona (Figure 4).

Figure 5 shows the heating output of this pair of collectors as a function of solar input during February 1981. This curve is typical for the input-output relation of the integrated zeolite collector, both for heating and cooling. The collector will provide about 1.5 kWh/m^2 of cooling on a sunny day. For an average single-family home, 60 m^2 of collector area will provide the heating, cooling, and hot water needs in almost any climatic area in the United States.

Inasmuch as the zeolite system could be used for both agricultural heating and cooling, such a system would permit a much shorter period for repayment of capital costs than a single-application system, making the combined system more attractive to potential users. This will be true in particular for dairy farms where there is a constant need for hot water for washing and sterilizing as well as chilled water for the cooling of milk and milk products. Further agricultural applications for which interest has been shown is for the heating and cooling of hen houses and pig fattening facilities, and for walk-in coolers for immediate field refrigeration of perishable fruits, vegetables, and fish.

Milk Cooler

The integrated solar-zeolite collector was recently adapted to the needs of dairy farmers in less developed nations. Because no heat output was necessary, the collector was equipped on the back with air-cooled condenser fin-pipes. The condensed vapor during the desorption cycle then ran by gravity into the flooded evaporator, in close analogy to the solar icebox. A schematic diagram of the solar milk cooler is shown in Figure 6. During the design stage, the milk cans were immersed in a basin of cool water which was further refrigerated by the evaporator of the solar collector. A more thermally-efficient solution would have been to immerse the evaporator directly into the milk can; however, this solution was rejected for sanitary reasons and because of the problem of vacuum-tight flexible joints needed for a movable (immersible) evaporator. The area of the solar collector was 1.5 m^2, and on a sunny day with 35^0 to 40^0C ambient air temperature, it cools 60 liters of milk (two 30-liter cans) from 35^0C to 15^0C for a minimum cooling load of 1200 Kcal/day.

The final version of the solar milk cooler is shown in Figure 7. The basin has a volume of 165 liters of which 60 liters is the volume of the milk cans. It is insulated with 15 cm of closed-pore polyurethane insulation having a loss coefficient of 0.2 $W/m^{2 0}C$. A cover, also made of 15 cm polyurethane, prevents losses from the ambient air after the milk cans have been immersed in the basin. A PVC wall with proper openings was installed between the evaporator pipes and the milk cans. This wall established thermosyphon circulation in the basin during the cooling cycle and thereby reduced temperature variations within the basin and milk cans to less than 0.5°C. Such a milk cooler can operate in two alternative modes: (1) During the night, the water in the basin without the milk cans will cool to about 7°C. After the milk cans (at 35°C) are added during the day, the temperature of the combined system will slowly approach 15°C. (2) The milk cans (at 35°C) are placed during the evening in the basin which is at a temperature of 15°C. The temperature of the combined system will then approach 22°C, but will drop during the night to 15°C. In either mode the cooler will treat the milk from one or two cows per day, thereby preventing spoilage of milk before pick-up. Because the cooler uses only solar energy, it can be used in areas where electricity is not available or where it is unreliable or very expensive. A further possible modification of the milk cooler will have pipes that run through the zeolite panel to provide auxiliary heat whenever the sun is not shining. The farmer could then start a small fire from straw, cow dung, or other native fuels and let the hot gases and smoke from the fire pass through the pipes in the zeolite panel, thereby heating the zeolite and causing desorption.

Zeolite Solar Cooler

A walk-in zeolite cooler has a refrigerated volume of $15.4 m^3$ and internal dimensions of 2 x 4.8 x 1.6 m. The walls and roof area of the cooler are constructed with 125 mm thick polyurethane insulation and have a heat loss coefficient of $0.2 W/m^2 {}^oC$. The total daily cooling load is about 6000 Kcal corresponding to 75 kg of ice per day at 40°C ambient temperature. The zeolite cooling system uses the same principle of operation as the solar refrigerator. The only differences are that the solar collectors are much larger, i.e. 2.44 m long and 1.2 m wide, and four separate, independent, cooling modules are employed, each consisting of a solar collector, an air-cooled condenser, and an evaporator. Each module is evacuated and sealed separately, thus improving the reliability of the system because a vacuum failure would disable only one-quarter of the total system. Each module can produce about 25 kg of ice per day for a system total of 100 kg ice per day with an average solar input of 4500 Wh/m^2 day. This output compensates for the load due to heat losses and provides an additional 25 kg ice per day for losses due to door opening and closing and for the cooling of introduced produce at ambient temperature.

Figure 8 represents a photograph of a prototype unit of the walk-in cooler which was tested in Kenitra, Morocco for one whole year in 1984. During the summer months, the inside temperature remained below 7°C, reaching a low of 3°C, while the outdoor temperatures routinely exceeded 40°C. The cooler is intended for on-site refrigeration of perishable produce and tropical fruit. Its major application will probably be in locations where energy costs are high and electricity is unavailable, unreliable, or expensive. It may find application in U.S.-affiliated islands for in-the-field refrigeration of high-cost, perishable products. The refrigeration units may also be mounted on flat bed trucks or as modules on insulated trailers to provide mobility for the system.

The walk-in cooler may be of great importance to the fishing industry and especially for the refrigeration of fresh fish and other seafood in remote fishing villages on tropical islands. In such circumstances, it is impractical to have a regularly scheduled pick-up by refrigerated trucks because the daily catch of the fishermen is unreliable and unpredictable. The walk-in cooler would provide temporary refrigerated storage; and, whenever the daily catch is of sufficient magnitude to justify refrigerated truck pick-up, it would prevent spoilage of the seafood until the summoned truck has arrived.

Solar Zeolite Freezer

While water vapor is the most efficient working fluid for applications at temperatures between 0°C and 10°C, at evaporator temperature much below 0°C, the water vapor pressure of water becomes very low and the efficiency of the zeolite cycle drops rapidly to unacceptably low levels. It is necessary, therefore, to look for other refrigerants in order to cover the range of evaporator temperatures less than -18°C (0°F). The candidate refrigerant has to exhibit large heat of vaporization and, after careful consideration of chemical stability and the thermodynamic properties, the methanol/zeolite combination was chosen for the solar deep-freeze application.

In order to prove feasibility, one of our standard iceboxes was modified for methanol testing. For this purpose, we retained the glass evaporator and calibrated its volume for methanol since its density is different from water. Next, an insulated box, made of 5 cm rigid polystyrene foam was built around the glass evaporator to form a small freezer compartment in the refrigerator. A thermocouple was attached to the surface of the glass evaporator and a second one measured the freezer compartment air temperature. The zeolite was activated and the unit was then charged with 2 liters of methanol and cycling tests were started.

On the first day the evaporator temperature reached -18°C while on the second day our meter, which measures only to -20°C, was out of scale. A different thermocouple meter was then used and on the third day temperatures of -24°C were observed on the outside wall of the glass evaporator! The inside methanol temperature was lower than that. The feasibility of negative temperature refrigeration was confirmed. Since the heat of adsorption of methanol is only about half that of water, the zeolite loading (50 kg/m^2) was too low for optimum performance. It was estimated that the zeolite loading would have to be increased to 75 to 80 kg/m^2 in order for the panel to be able to receive 4.5 kW/m^2 without overheating. Even under those conditions, which were not optimum, about 1.5 lb (0.7 liters) of methanol was recycled producing a net cooling in excess of 750 Btu (190 Kcal) at -20°C. It is expected that the output of an optimized icebox panel will be about one-third larger or about 1000 Btu (250 Kcal) per day. The overall efficiency now is about 8.5% on a daily basis, however, for the optimized panel it is expected to go up to about 12% or close to the total daily efficiency of the solar refrigerator. A picture of the negative temperature freezer with a view of the frost-covered evaporator is shown in Figure 9.

While the results from the negative temperature tests are much better than our most optimistic expectations, a number of problems remain to be resolved which we hope to do in a future development program. First, the optimum zeolite loading will have to be determined and the exact activation procedure established. Second, the long term stability of the system has to be established. Some tests we have performed indicate that at 200°C the zeolite reacts with the methanol and carbon is deposited on the zeolite. Therefore, we have some serious concerns about the operational stability of the system over a period of many years. Resolving these problems will be mandatory before the actual design and construction of a full-scale prototype.

Non-Solar Zeolite Applications

The false (but growing) public perception of an "end of the energy crisis" coupled with the high interest rates prevailing in the past 3 to 4 years have made solar cooling projects economically unattractive because of their high initial costs. Consequently, we have focused our present R&D effort on indirectly driven zeolite systems. Reducing the cycling period from 24 hours (dictated by the length of the solar day) to one hour or less has reduced the size of the system (and its initial cost) by a factor of 25. Furthermore, increasing the maximum zeolite temperature from 250 to 350°F increases the cooling capacity per cycle 2 to 3 times compared to direct solar drive thereby reducing the size, weight and cost of the system by almost a factor of 100. External energy, however, has to be supplied during operation.

We have just recently completed the development and testing of a breadboard prototype system of about 12,000 Btu/hr capacity driven by hot oil at 300 to 350°F temperature. The potential sources of heat for this system range from conventional fuels (natural and LP gas, oil, wood, coal, etc.) to waste heat from internal combustion engines and industrial processes to concentrating solar collectors. The weight of a 3.5 kW (1 ton) system in final product version is expected to be about 100 kg at a price of about $300 and overall operating efficiency (coefficient of performance, or COP) above 110%. This system will be a natural choice for mobile cooling applications such as refrigerated trucks and boats propelled by internal combustion engines with exhaust temperatures above 200°C (400°F). The system is expected to reach the marketplace in about 2 years and to have large market penetration by the year 1990.

Estimated Purchase Costs, Upkeep and Maintenance Requirements

Most of the products described so far have been produced on a small scale only (over 100 solar refrigerators, integrated collectors, and other devices) and, therefore, have experienced large labor costs. Reasonable estimates are available, however, for the price of mass produced units mainly because of a joint venture agreement with a large Japanese manufacturer (which was recently revoked) which did a detailed study of material and labor costs at different volumes of production and degree of automation. Our best estimates for a production volume of 10,000 m^2/year of collectors are between $300 and $400 per square meter which results in the following product costs per square meter of collector and cooling output:

1) Solar heating/cooling systems - (10^{o}C operation) - output of 1.5 kWh/m^2day at \$300/m^2 or about \$200/kWh/day or \$5/watt.

2) Solar refrigerator - (5^{o}C operation) - output 0.75 kWh/m^2day at \$300/m^2 or \$400/kWh/day or \$10/watt.

3) Solar deep freeze - (-18^{o} operation) - output 0.5 kWh/m^2day at \$300/m^2 or about \$600/kWh/day or about \$15/watt.

4) Solar walk-in cooler - (5^{o}C operation) - output 0.7 kW/m^2day at \$400/m^2 or \$533/kWh/day or about \$13/watt.

5) Non-solar cooling - ($5-10^{o}$C operation) - at about 10¢/watt initial cost (for capacities of 3-15 kW size) plus fuel costs of between 2.5¢ and 10¢ per kWh (\$7 to \$30 per million Btu). The result of waste heat operating conditions should be no additional fuel costs.

The upkeep and maintenance requirements of the solar systems (with the exception of the deep-freeze where further development is necessary) are minimal -- a possible purge of noncondensable gases once every 3 to 6 months -- and even this requirement is expected soon to be relaxed to only 2 or 3 purges during the 20-year lifetime of the system.

The presence of pump and motors in the non-solar system will require regularly scheduled maintenance for lubrication on a monthly basis and moving parts replacement according to accepted maintenance schedules by the industry. The required skills for the upkeep and maintenance work are minimal and so far have been easily found in all third world countries where our products have been operational.

Operational Experience and Suitability for Tropical Environment

The largest operational experience is available for the solar refrigerator which has been marketed since 1979 and has been used extensively in the third world. Units have been shipped to Mali, Sudan, Morocco, Saudi Arabia, Bahrain, United Arab

Emirates, and Botswana in Africa, Pakistan, India, Philippines, Singapore, Taiwan, and Japan in Asia, Australia, Hawaii, Virgin Islands, and France, Italy, Austria, Germany and Sweden in Europe. In addition, the World Health Organization in Geneva, Switzerland has evaluated the unit for vaccine and serum storage as part of its immunization program and found the technology to be the most promising for its needs.

This unit was originally designed as a beverage cooler for the backyard leisure living in the southwestern USA and therefore it performs best in dry, semi-arid climates with high solar daily input and large day-to-night ambient temperature differences. When the unit is used in the high-humidity tropical climates, two separate factors reduce its performance: 1) The daily solar input is reduced by fog, haze, and clouds in the rainy season while the cooling demand is increased because of the moisture infiltration during door opening; and 2) the day-to-night ambient variation is reduced due to the high moisture content of the air from about 20°C to as low as 5°C in places like Madras, India. For such climates the unit has to be redesigned with lower thermal mass of the collector (25 kg zeolite/m^2) and additional heat losses from the zeolite panel (via thermal diode) during the night. Even with these changes, the performance under worst conditions may be only 0.5 kWh/m^2day, i.e. 30% lower than under optimum conditions.

The solar heating/cooling system exhibits smaller adverse dependence on tropical high-humidity conditions since it is designed for large night heat-losses (air circulation around the zeolite panel at night) and partly cloudy skies as often encountered during the fall, winter and spring seasons in the USA. Only minor modifications will therefore be necessary to operate successfully in tropical island environments. Most units of this system have been tested only in the western USA and the Boston area with the only overseas experience being provided by the European countries and Japan; however, this limited experience confirmed the small effects of humid climates on its performance.

The only prototype of the milk cooler was tested by us in this country and by a Swedish university under controlled ambient conditions (the test funded by our Swedish client) and therefore we have no available operational data for tropical climate operations.

The zeolite deep freeze prototype as well as the breadboard prototype of the indirectly heated (non-solar) zeolite cooling systems have only been tested by us in our facilities and no operational experience is available in tropical climates. Because of the similarity between these prototypes and the previously-discussed systems, however, it is expected that the same limitations will be applicable in the prototype's case.

Two solar walk-in coolers have been built and tested so far: the first unit in Dubai, U.A.E. has been successfully operating since 1982 with only the minimal maintenance discussed previously and it will soon be moved to Saudi Arabia for further testing by the university there. The second unit was tested for 1 year (1984) in Kenitra, Morocco after which it was disassembled and shipped to France as required by the custom authorities in Casablanca. During the test period, the unit performed as designed, producing ice continuously with quarterly maintenance and keeping internal temperatures of 3 to 7°C even during the summer months. The climatic conditions in both locations are semi-arid and therefore the same comments made for the solar refrigerators above will be applicable to this case.

Social and Cultural Factors Affecting the Use of this Technology

The major cultural factor affecting the use of the technology is the fact that over thousands of years societies have developed food preservation techniques based mainly on drying, smoking and salting processes which have resulted in acquired tastes for the food products. For example, smoked fish, ham and sausage are considered desirable and even with present food preservation technology, smoked flavor is added to these foods to satisfy the taste of the customer. Salted butter is preferred in most countries (except for use in some desserts) and cheese without salt is unthinkable to most people. Furthermore, the most often received comment from third world countries has been that while solar refrigeration may extend fresh meat availability from 2 days to 2 weeks, the real need is for 6-month availability (until another pig is raised and slaughtered), i.e. the real cultural need is deep-freeze technology.

The most important social factor has consistently been the fact that the people who most need the technology can least afford it. In third world countries where the infrastructure (roads, electric power, repair services) is minimal or nonexistent, we find the largest need for solar cooling and refrigeration equipment; however, the poor Indian farmer who has one or two cows and badly needs our milk cooler has an annual income of a few hundred dollars and can never buy one unit costing three times as much unless the unit is given to him free or heavily subsidized by governments or institutions. As the World Health Organization recommends, the People's Republic of China needs at least one vaccine refrigerator in each of the 300,000 villages there which have no electricity; however, even at a minimum mass production cost of $250 per unit, it will cost their government $75 million and such hard currency resources are simply not available while local manufacturing under licensing agreement raises many other questions of royalties, their basis for calculation, and the possibility for repatriation in convertible currencies.

Our conclusions therefore are that the technology is only applicable with heavy subsidies or capital outlay by government or institutions and, even in this case, it is justifiable only if it will result in new sources of income and resource utilization not previously available without this technology. This usually indicates larger systems of communal size and use such as central food storage and processing facilities which results in new cash crops or processed food products rather than individual units which may benefit the lifestyle of individuals and their immediate families.

APPLICATIONS

Livestock Cooling Systems

It has been established (ASHRAE Handbook of Fundamentals, Ch. 9, 1977, Handbook of Applications, Ch. 22, 1978) that optimum conditions for livestock breeding, feed utilization and dairy and egg production require that ambient temperature is kept below $24^{o}C$ ($75^{o}F$) and the relative humidity below 75%. The zeolite heating/cooling system is very well suited for this purpose since it was originally designed for human space conditioning which has considerably more stringent requirements. Operating at higher evaporator temperature ($65^{o}F$ versus $45^{o}F$ for residential applications) increases the nominal capacity of the system by about 10%. The economic viability of the system should be determined by the livestock productivity loss which is about 90% of normal for cows and 80% of normal for laying hens at $30^{o}C$ ($85^{o}F$) ambient temperature.

The cooling capacities required are: 1.5 kW per cow, 0.7 kW per pig, and about 30 watts for laying hens. From the reduction of productivity and the price of the product at a given locality, the economic viability of the zeolite system can be established using the zeolite system cost of about $5/watt and a 20-year average system lifetime. For example, assuming one egg per day, a hen will lay in 20 years 7,300 eggs under optimum conditions, but 1,460 less eggs at $30^{o}C$ temperature. A 30-watt zeolite system will cost $150 and will be cost-effective at an egg price of 10¢ or more. Where photoperiodism (length of daylight) is practiced in order to increase egg production, savings will be even higher. The zeolite system is compatible with roof water catchment systems since the zeolite collectors are usually mounted on top of regular roofs and any rainwater falling on the collectors will drain back on the roof.

Food Refrigeration Systems

The solar refrigerator and walk-in cooler are the technologies of most immediate application and widest possible use. They maintain an inside temperature of 3°C to 7°C and require no external parasitic power. The major benefits from the use of the technology will be the increased storage life of food products. The list is long, but the most important products are:

> Uncut, fresh meat at 3°C to 4°C has a storage time of 10 to 14 days for beef, lamb and veal, 6 to 8 days for pork;
>
> Cut meat has a considerably lower life -- 3 to 5 days maximum;
>
> Poultry at 2°C has 14 days life, and at 10°C it has 5 days of storage;
>
> Milk and fresh dairy products at 4°C have a life of 10 to 13 days;
>
> In general, meat, milk and poultry can gain 2 weeks of extra shelf life;
>
> A large group of fruits and vegetables including cucumbers, melons, pineapples, mangos, avocados, green beans, peppers, tomatoes, etc., have a storage time of 2 to 3 weeks at 7°C to 12°C and can therefore easily benefit from this technology or variations of the heating/cooling zeolite systems.

The other group of perishable fruits and vegetables, however, requires storage temperatures of 0°C to 4°C (the same as meat and milk) and therefore benefits from the refrigerator technology. This group includes citrus fruit, all berries, pears, peaches, asparagus, broccoli, cauliflower, sweet corn and most leafy vegetables, and the extended storage time for this group is from 2 weeks to a month. The hydrocooling method (contact with chilled water at 1°C to 4°C is also very beneficial for fast initial cooling of these perishables and the zeolite system can provide large quantities of chilled water efficiently. When installed on flatbed trucks, the system can be transported to the field for immediate cooling and storage of these perishables.

Fish requires immediate icing after it is eviscerated after which it can be stored for 10 to 15 days at 2°C ambient (as long as the ice has not melted). While both the zeolite refrigerator and walk-in cooler generate ice during the cycle, this ice is under vacuum and therefore is unavailable for fish icing. The units can be used, however, for the subsequent storage of the iced fish. The production of externally accessible ice requires lower evaporator temperatures and will be available when the zeolite freezer system development is completed.

Another method of using this technology for storage of fish and shellfish is the immersion of the live product in chilled sea water at about 1°C to 4°C temperature. This method results in an additional 3 to 5 days storage period before the fish is eviscerated and iced and the zeolite technology is capable of producing large quantities of chilled water at this temperature.

The freezing of fish, meat, poultry and vegetables can increase the storage life to 24 months at -23°C, however, this method also has to await the completion of the zeolite deep freezer development.

There are no known adverse health effects of the technology and the potential benefits range from increasing the storage life of fresh crops for local consumption to permitting the marketing of perishable crops on islands without electric power or other cooling facilities. The availability of refrigerated warehouses may permit the storage until refrigerated shipment containers arrive of perishable products which otherwise could not be marketed by remote islands without infrastructure and therefore increase the living standards and quality of life of the local population.

Mobile Zeolite Refrigeration

As mentioned earlier, solar powered zeolite refrigerators and walk-in coolers can be installed on flatbed trucks or trailer beds for "in the field" usage, however, the weight of such systems (about 100 kg/m^2) limits this use to only medium and large boats.

The new technology being developed, using indirect heating of the zeolite by the waste heat of internal combustion engines, reduces the weight of the zeolite system by a factor of 30 to 100 and since most mobile applications are propelled by internal combustion engines, the new technology seems to be custom tailored for mobile applications. This includes refrigerated trucks and boats as well as ships which can be used to bring the perishable crops from the "field" to market or processed foods to the customers.

The durability of the solar zeolite systems is limited under bad road or sea conditions because of possible glass breakage in the collectors. With the indirectly heated zeolite technology the durability is excellent since the hot-fluid-to-zeolite heat exchangers are designed for rough handling and the complete system is made entirely of metal, thus resembling existing vapor compression machinery.

Processed Food Storage

Processed food differs very little from fresh crops in its refrigerated storage needs. Meat products usually require storage temperatures of 0^oC to 5^oC and have a storage life of 1 to 3 weeks. Dairy products require 4^oC temperatures and storage times are between 1 month for butter and milk to 12 months for cheese. Fruit juices at 0^oC to 4^oC have a life of 2 to 6 weeks while beverages and candy last from 3 months to 1 year.

The zeolite refrigerator and walk-in cooler technology is excellent for refrigerated storage of processed foods in the 0^oC to 5^oC temperature range. The frozen food storage will have to await the development completion of the zeolite deep-freeze technology.

On islands with high electric costs or limited availability of electric power, solar zeolite refrigeration technology will provide the maximum cost benefits to the food processing industry. Since the food processing industry is, in many cases, a source of large quantities of waste heat in the 200°F to 300°F temperature range, the much lower initial costs of the indirectly-heated zeolite technology may provide potentially much higher economic benefits and simultaneously reduce thermal pollution by the processing industry. The particular cases where this technology will be most useful will depend on the principal power sources of the processing plants and the amount of waste heat the plants generate normally during production.

ACKNOWLEDGMENT

The author acknowledges the valuable contribution of the employees of The Zeopower Company during the development, construction, and testing of the collectors. Special thanks are due to William LaFleur, without whose skillful assistance this work would not have been possible.

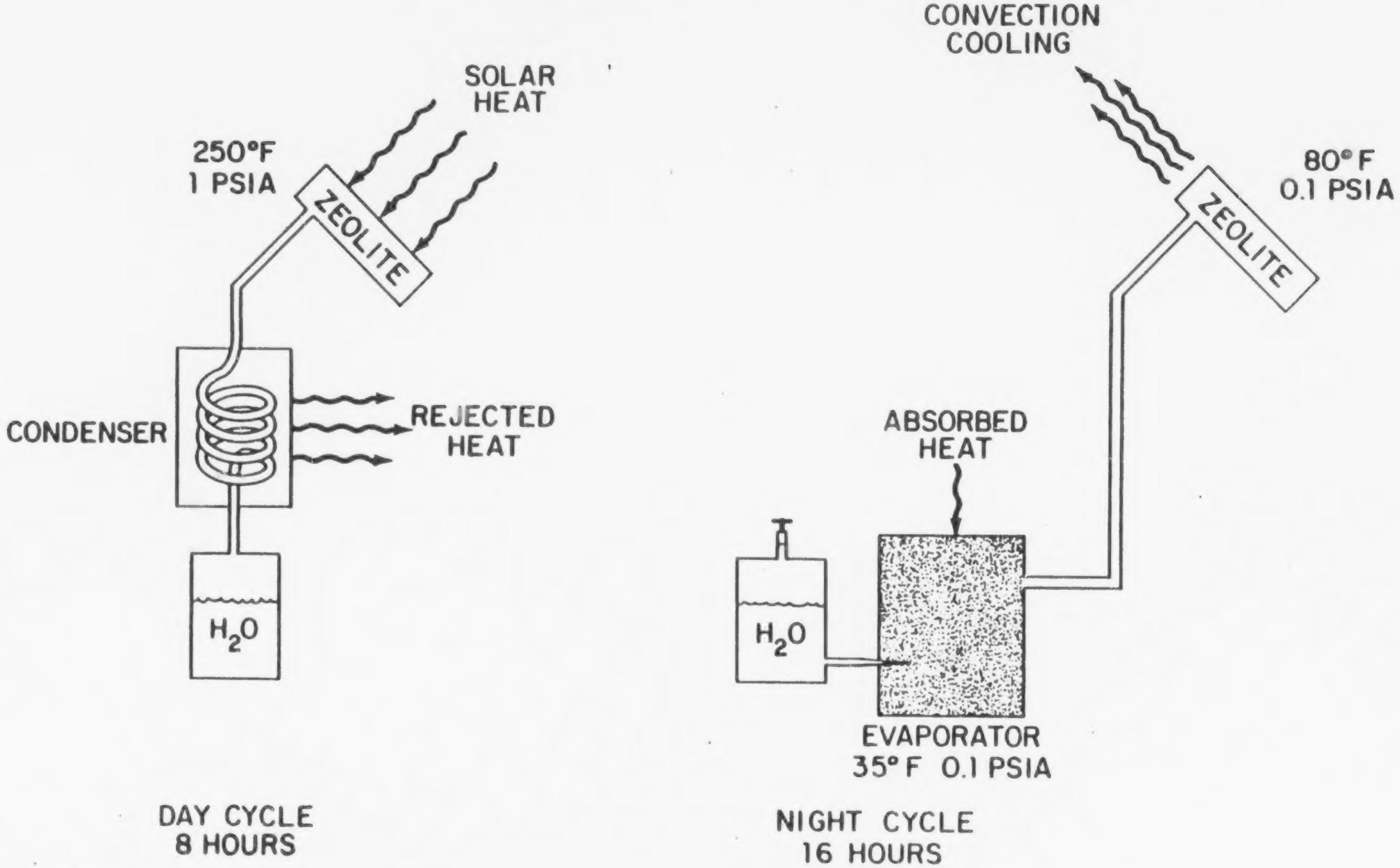

CONVECTION
COOLING
SOLAR
HEAT
250°F
1 PSIA
ZEOLITE
80° F
0.1 PSIA
ZEOLITE
CONDENSER
REJECTED
HEAT
ABSORBED
HEAT
H_2O
H_2O
EVAPORATOR
35° F 0.1 PSIA
DAY CYCLE
8 HOURS
NIGHT CYCLE
16 HOURS

FIGURE 1 SCHEMATIC DIAGRAM ILLUSTRATING DAY AND NIGHT CYCLES FOR ZEOLITE-WATER SYSTEM

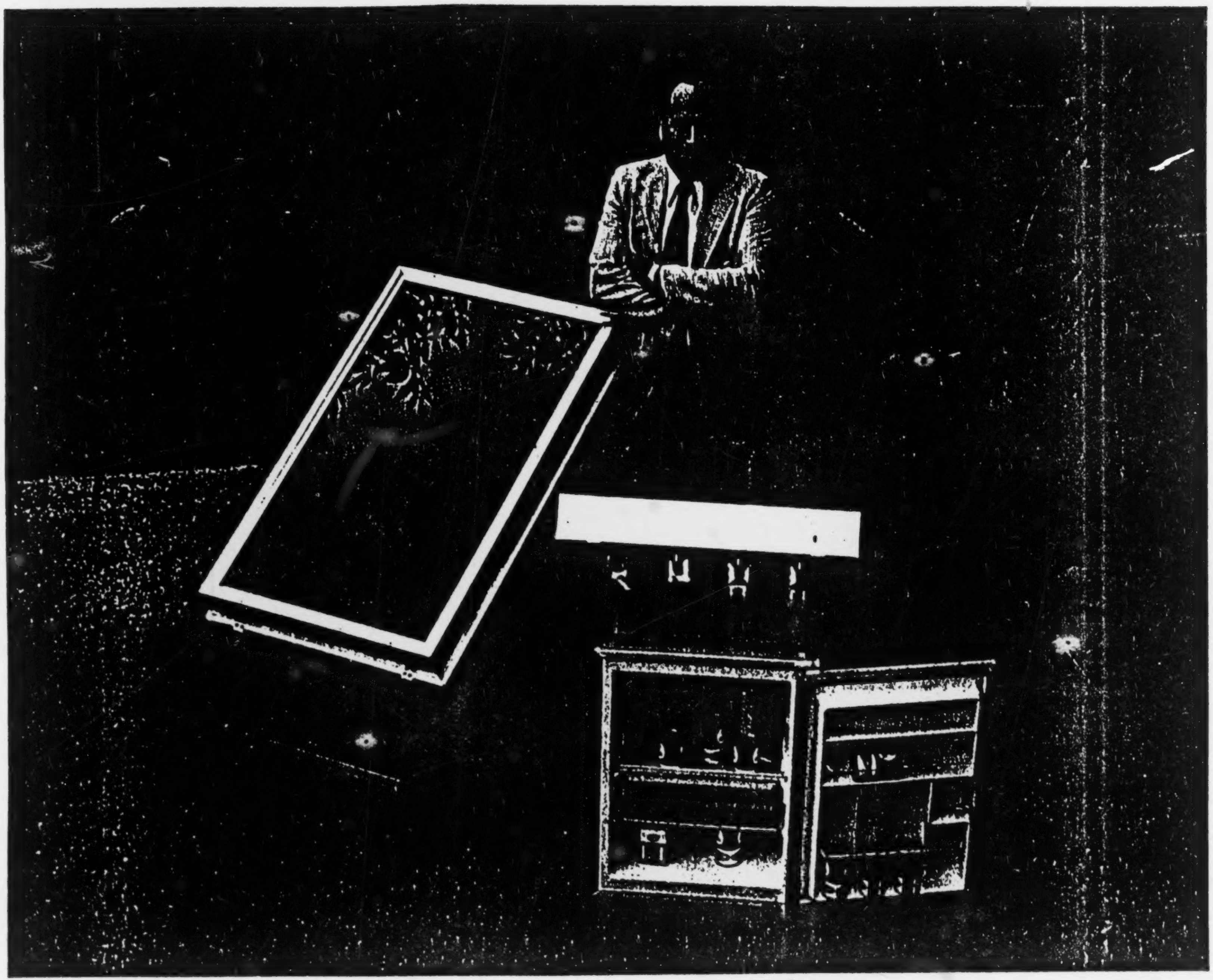


FIGURE 2 FRONT AND REAR VIEWS OF THE SOLAR ZEOLITE REFRIGERATOR

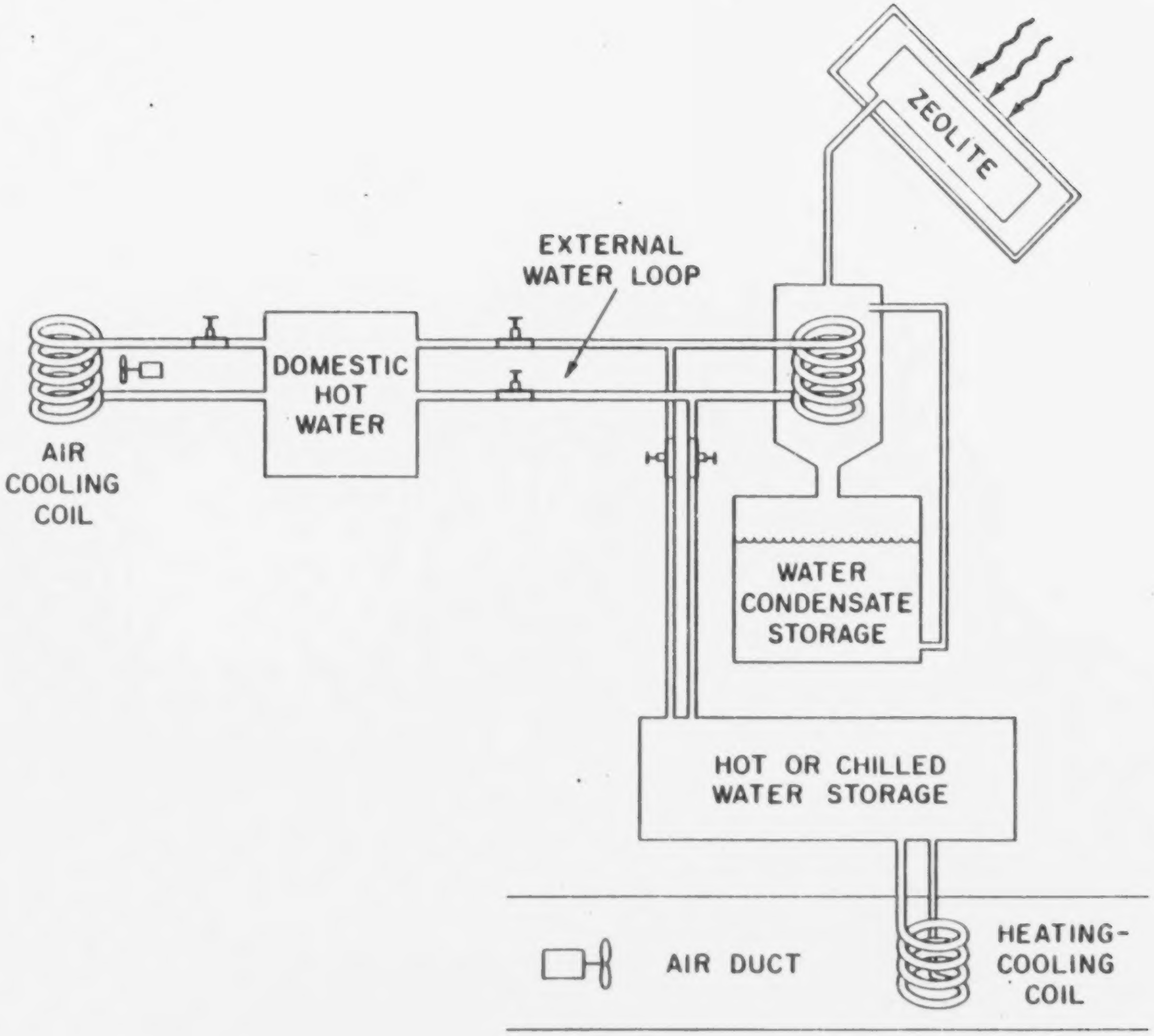

ZEOLITE
EXTERNAL WATER LOOP
AIR COOLING COIL
DOMESTIC HOT WATER
WATER CONDENSATE STORAGE
HOT OR CHILLED WATER STORAGE
AIR DUCT
HEATING-COOLING COIL

FIGURE 3 ZEOLITE SYSTEM FOR HEATING AND COOLING

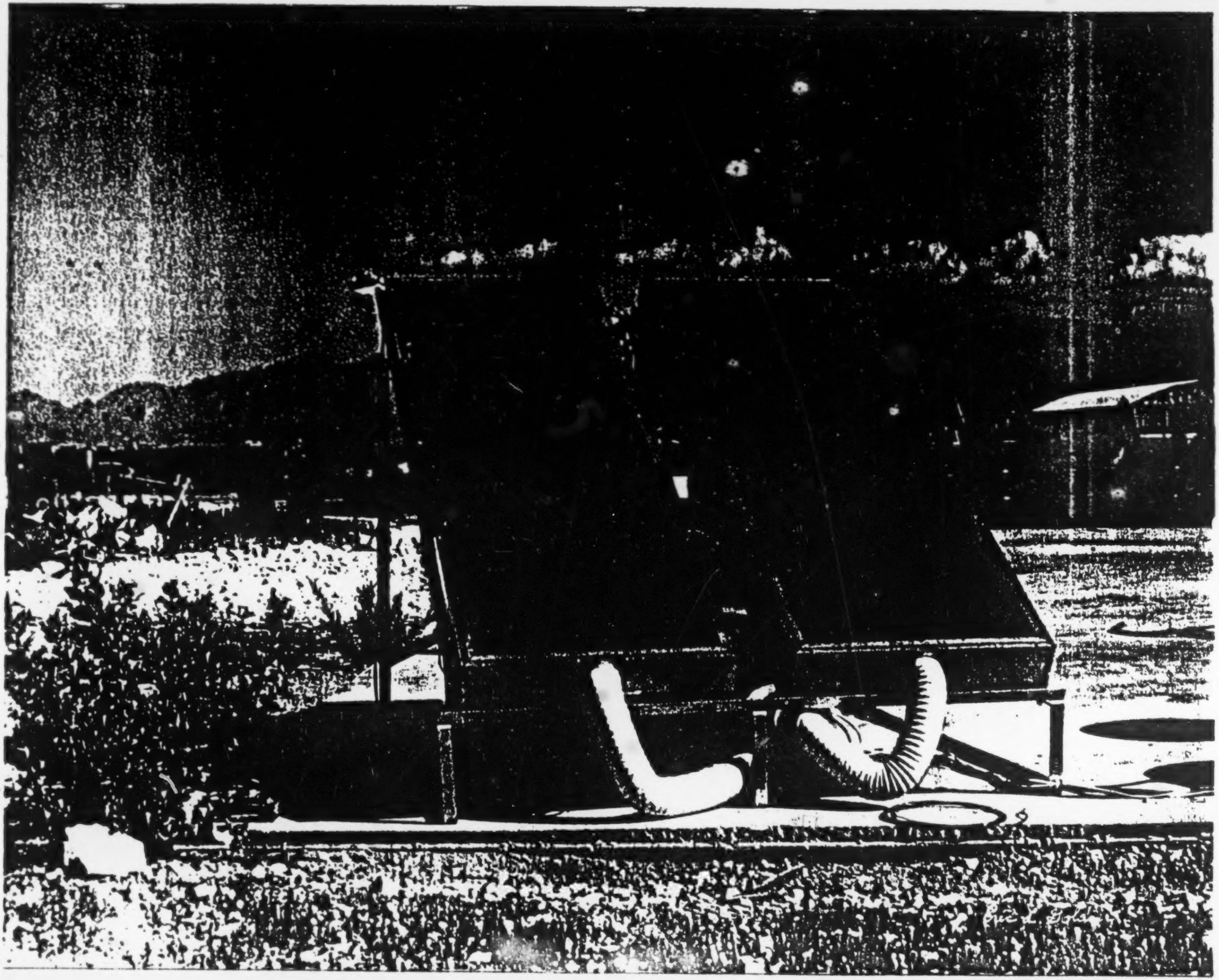


FIGURE 4 COLLECTORS UNDER TEST AT SITE IN TUCSON, AZ, USA

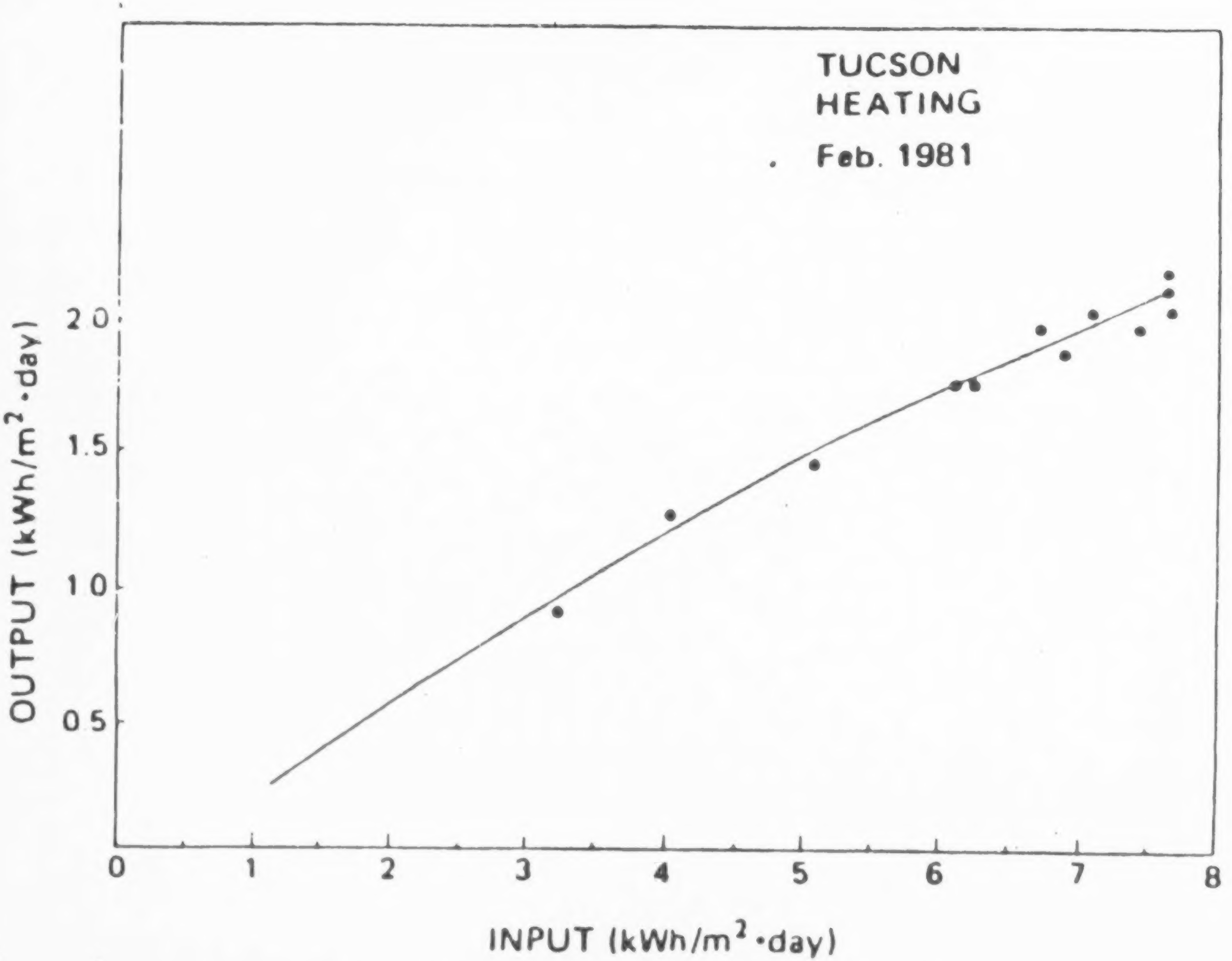


FIGURE 5 TYPICAL INPUT-OUTPUT HEATING CURVE FOR TEST COLLECTORS

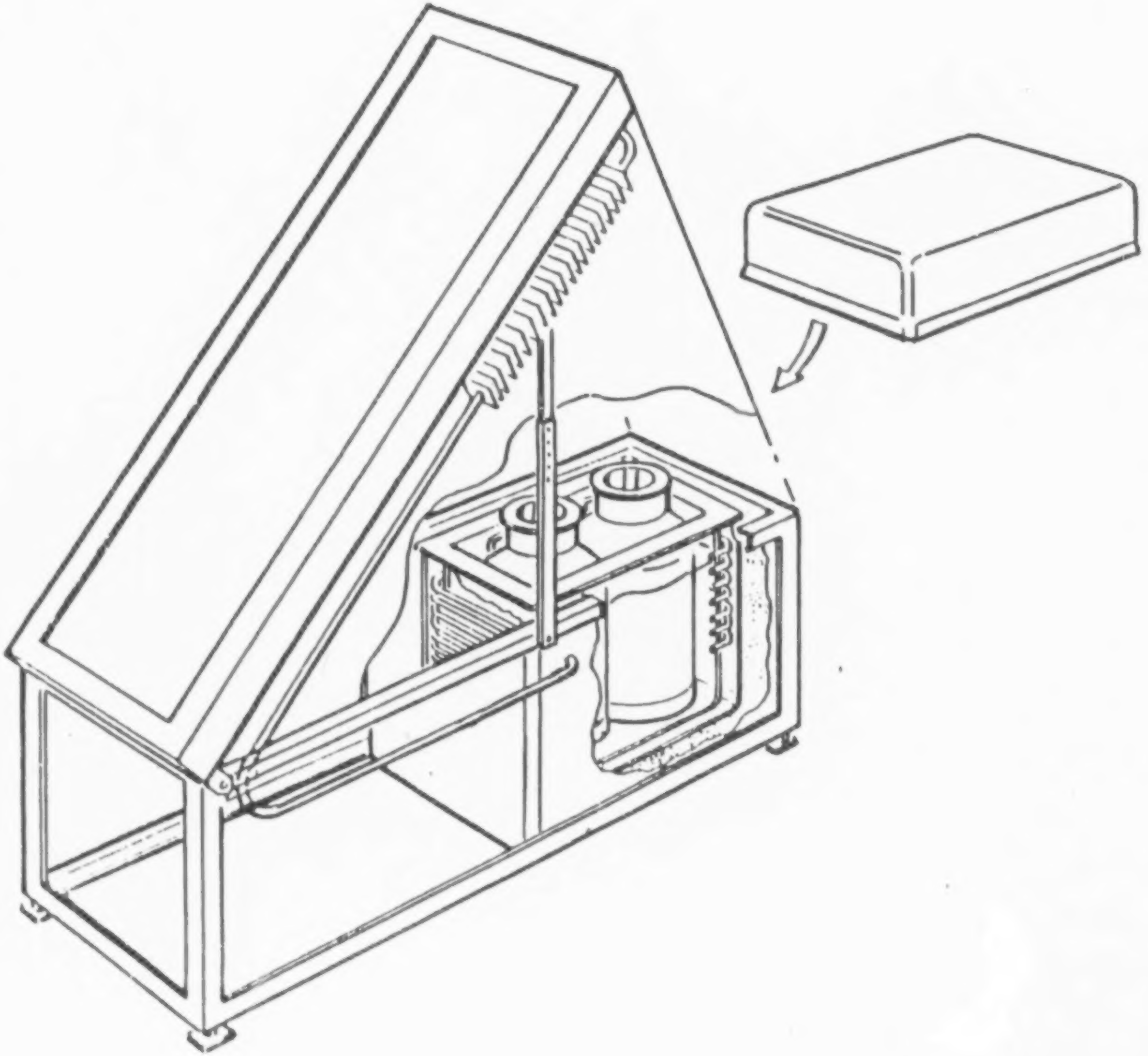


FIGURE 6 ARTIST'S CONCEPT OF SOLAR MILK COOLER

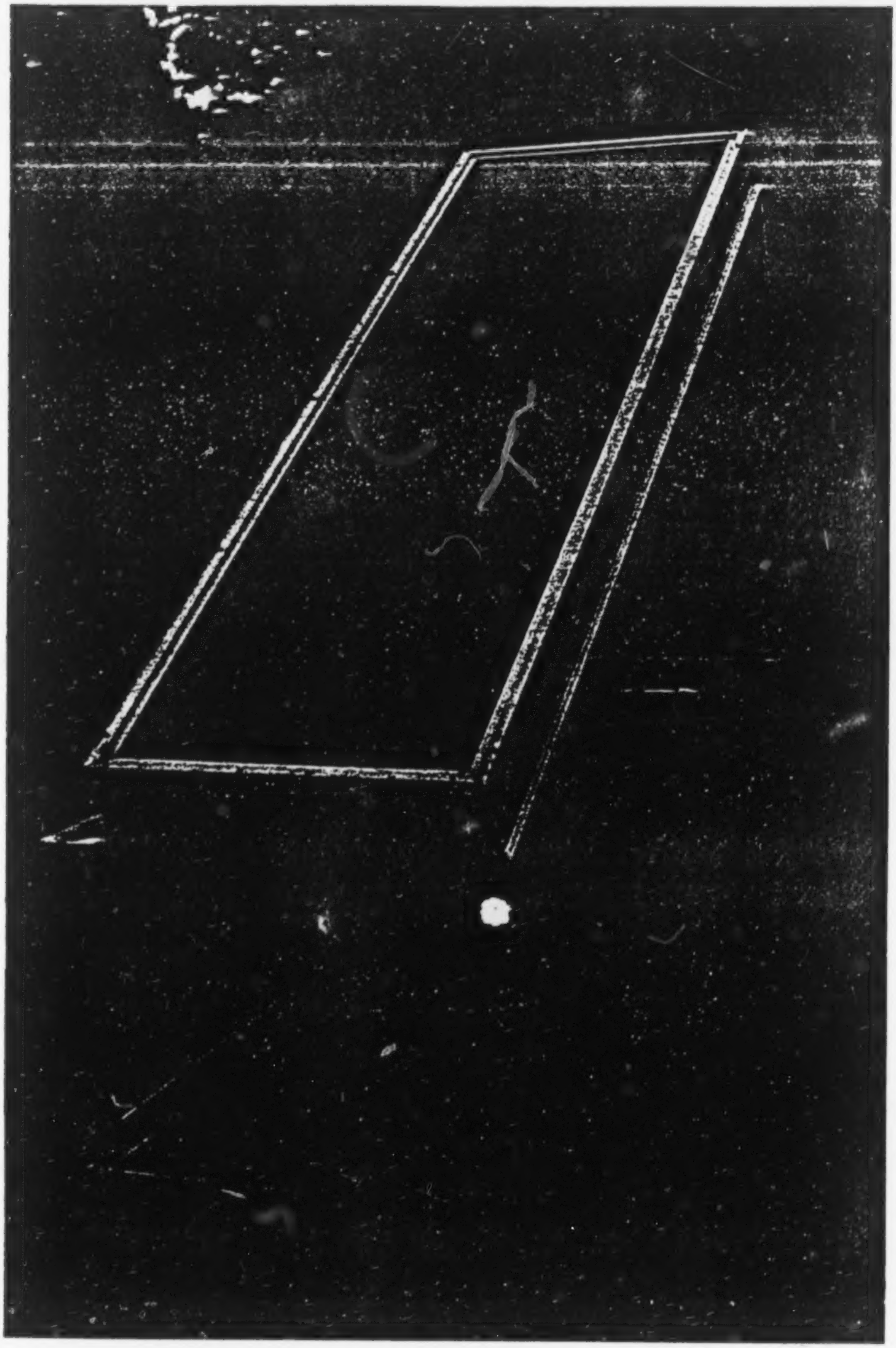
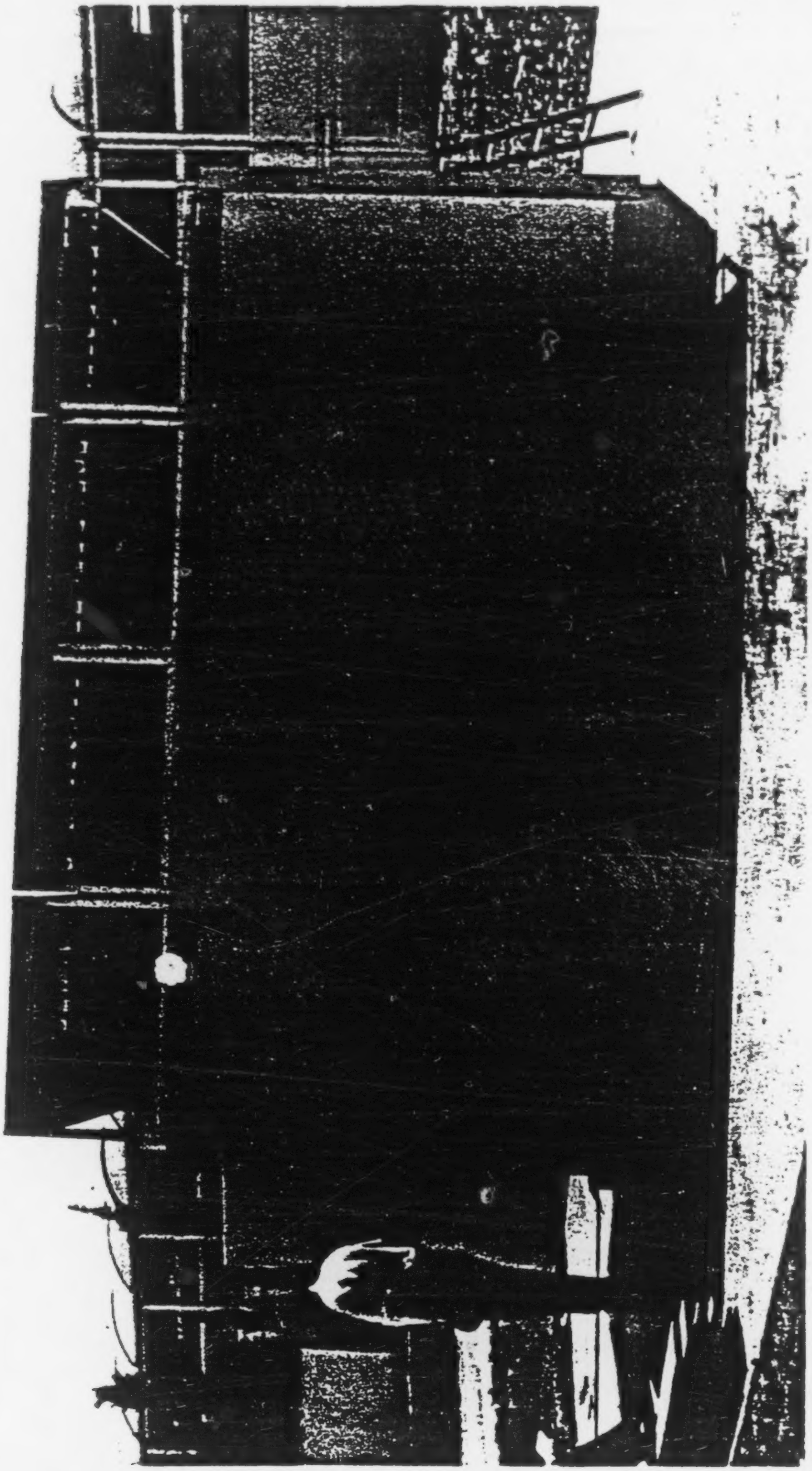


FIGURE 7 SOLAR MILK COOLER



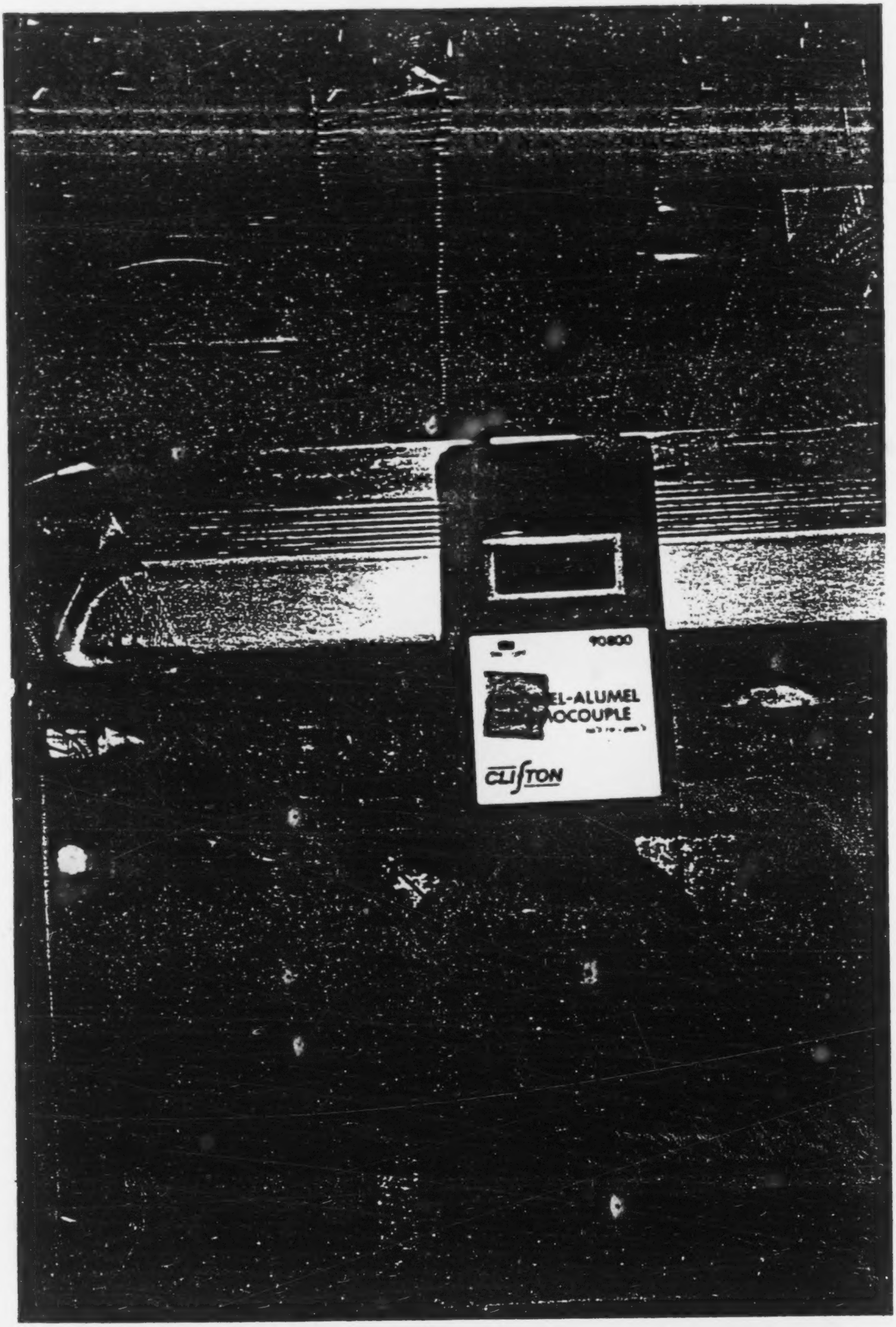

90800
EL-ALUMEL
OCOUPLE
CLIFTON

FIGURE 9 NEGATIVE TEMPERATURE FREEZER WITH VIEW OF FROST COVERED EVAPORATOR

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